# Esperimento LEA (Low Energy Antimatter): Antimateria a bassa energia

Quinto Incontro Nazionale di Fisica Nucleare

Laboratori Nazionali del Gran Sasso 9-11 maggio 2022

Luca Venturelli - Università di Brescia & INFN Pavia

# LEA Collaboration

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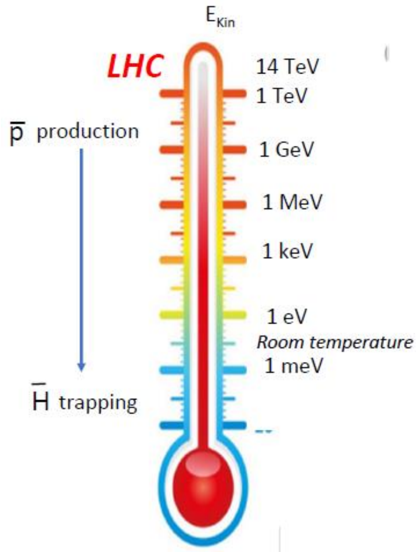


- 46 researchers
- 26 FTE
- 40% of FTE due to young people (PhD or post-doc) paid by institutes/univeristies

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# LEA project

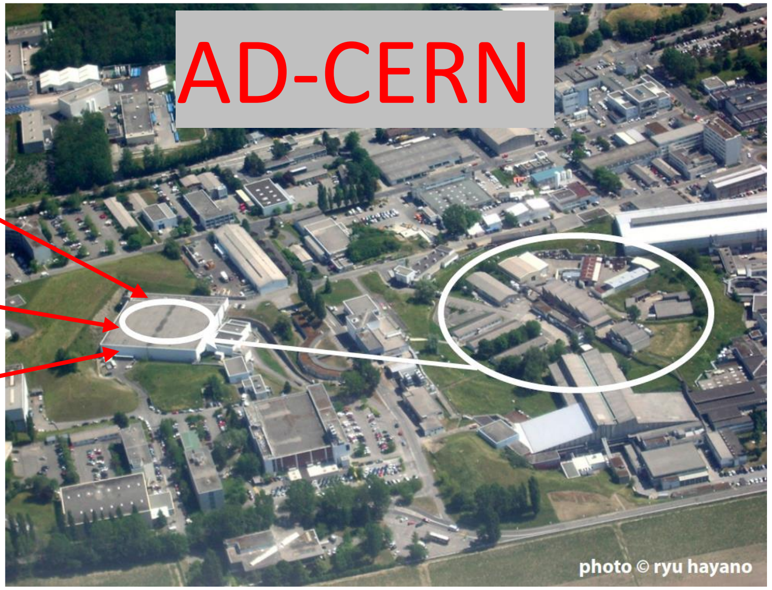
New project: approved by CSN3 in 2021 and started in 2022

Goal: to group **new** and already **existing experiments** working on low-energy antimatter:

- **AEgIS** funded by INFN since 2010
- **ALPHA** new (for INFN)
- **ASACUSA** funded by INFN since 2005
- **PsICO** spin-off of AEgIS (+ long-term expertise on e+ from UniTN)
- **QUPLAS** spin-off of AEgIS-ASACUSA (+ long-term expertise on e+ from PoliMI)

# LEA Experiments

- AEgIS   $\bar{p}$   e+   Ps   $\bar{H}$
- ALPHA   $\bar{p}$   e+   $\bar{H}$
- ASACUSA   $\bar{p}$   e+   $\bar{H}$




AD-CERN

- PsICO   e+   Ps
- QUPLAS   e+   Ps

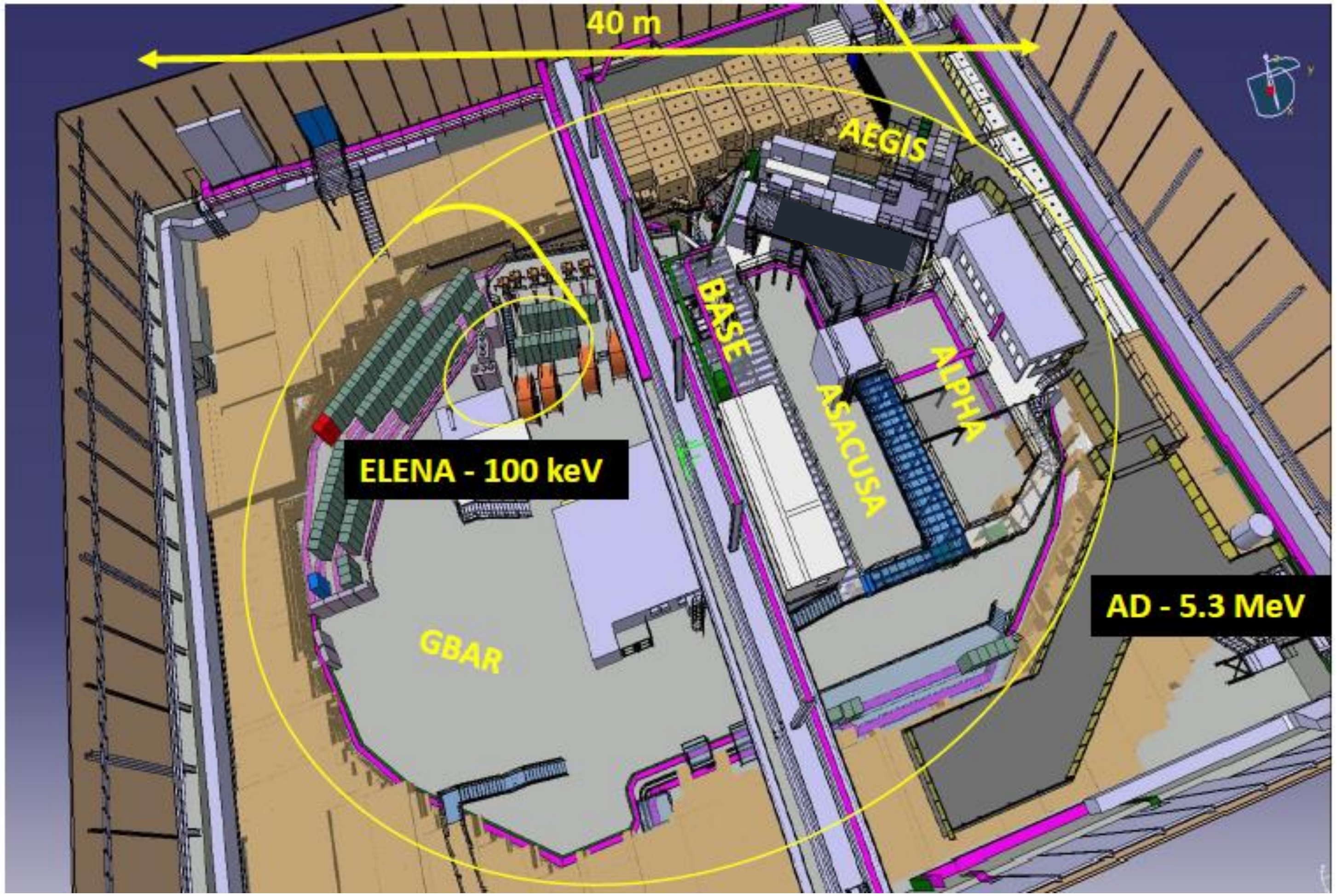
TIFPA-TN

L-NESS-CO

# EXPERIMENTS AT CERN

## AEgIS  ALPHA  ASACUSA

# Antiproton Decelerator (AD) & ELENA @ CERN




The only low-energy $\bar{p}$ source

**AD: 5.3 MeV**

Pulsed beam: $3 \times 10^7$ $\bar{p}$ every ~ 100 s

**ELENA: 5.3 MeV → 100 keV**

- 6 collaborations
- 60 research institutes/universities
- 350 researchers

- Fundamental properties of $\bar{p}$ (BASE)
- Spectroscopy of antihydrogen (ASACUSA, ALPHA)
- Test free fall/equivalence principle with antihydrogen (ALPHA, AEgIS, GBAR)
- Antiprotonic helium spectroscopy (ASACUSA)
- Nuclear physics (ASACUSA, AEgIS)

ELENA **from 2021 full operation**

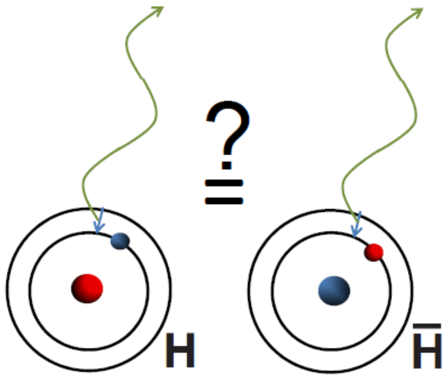
ADVANTAGES: ➢ x 10-100 $\bar{p}$ trapped per experiment ➢ 4 experiments run in parallel (24h/day)

# PHYSICS MOTIVATIONS

# Why study antihydrogen?

1) Precise matter/antimatter comparison

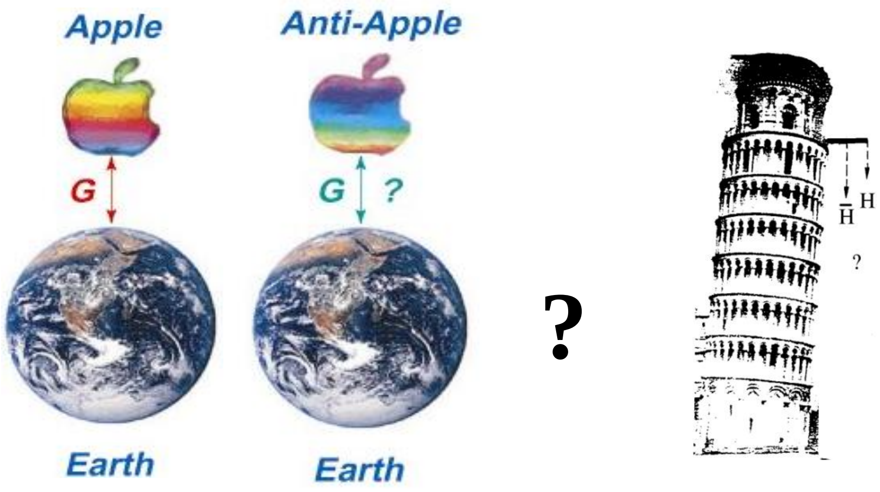
→ test of CPT symmetry




Spectroscopy of $\bar{H}$

2) Measurement of the gravitational behaviour of antimatter

→ test of WEP




Not possible with charged antiparticle

only with neutral system → $\bar{H}$ (or Ps)

# CPT theorem

The **CPT** theorem (1954): 50’s – Pauli, Schwinger , Lüders, Jost

**“Any Lorentz-invariant local quantum field theory is invariant under the successive application of C, P and T ”**

Assumptions:

- flat space-time, Lorentz-invariance, local interactions, unitarity, point-like particles

Consequences:

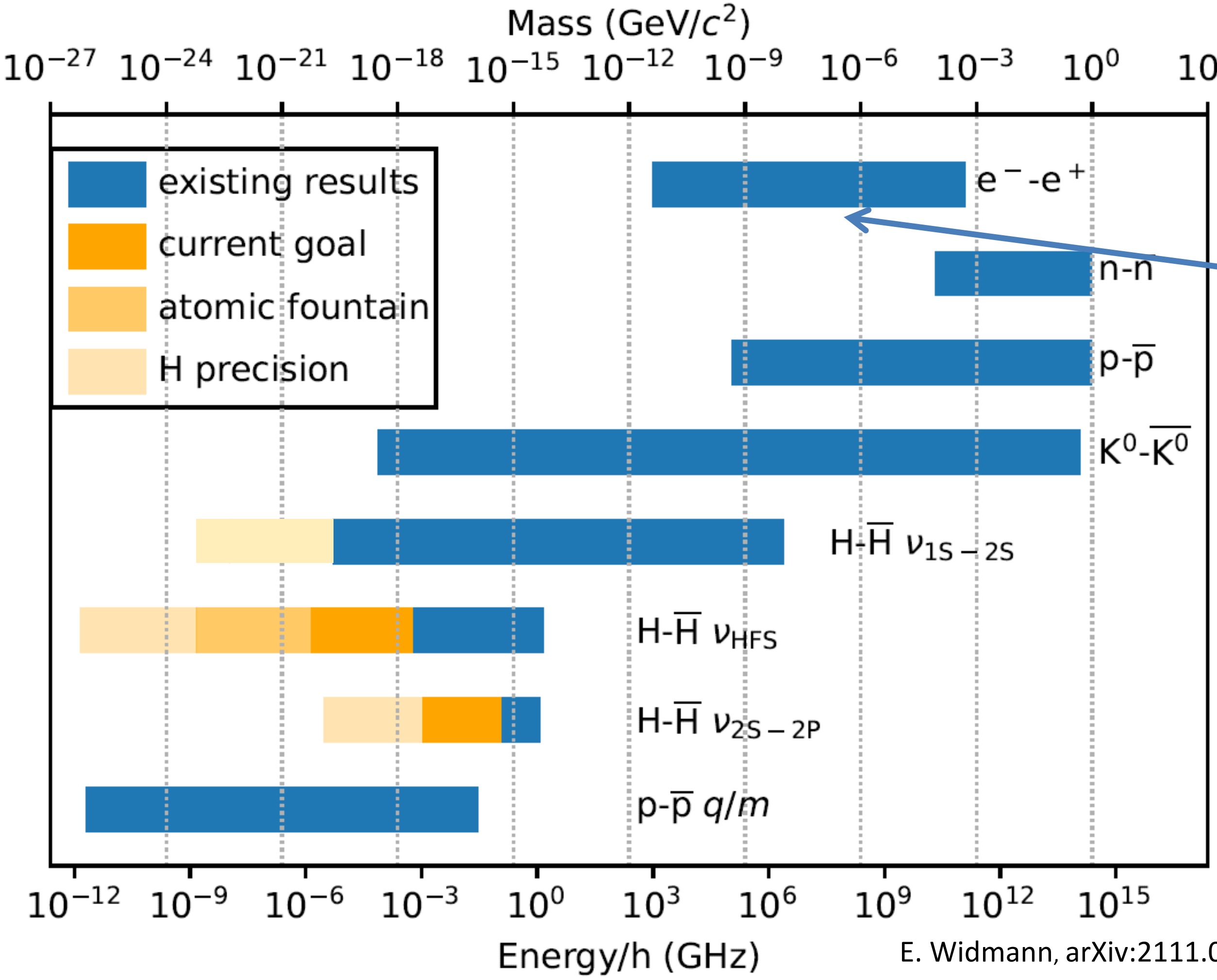
- particle/antiparticle: equal mass, lifetime; equal and opposite charge and magnetic moment
- **atom/antiatom: identical energy levels**

CPT invariance is inside the Standard Model

In string theory (and quantum gravity): assumptions non valid → CPT violations as a signature of string theory?

No measurement of CPT violation exists

# CPT tests: relative & absolute precisions




E. Widmann, arXiv:2111.04056v2

relative precision (length) = $\frac{\text{absolute precision (left edge)}}{\text{measured quantity (right edge)}}$

Considered "best CPT test":

$K^0 - \overline{K}^0$ $\Delta m/m \sim 10^{-18} \Leftrightarrow 10^5$ Hz

but **absolute precision** could be **relevant**

→ $H - \overline{H}$ highly competitive

Where CPT violation might appear is unknown

# CPT violation in Standard Model Extension

Indiana group, Kostelecky et al. (since 1997)

*Standard Model can be extended with CPT violation*

Standard Model Extension (SME) is an effective field theory which contains:
- General Relativity
- Standard Model
- Possibility of Lorentz Invariance Violation
- CPT violation comes with Lorentz violation

CPT & Lorentz Violating terms

Modified Dirac equation

$$(i\gamma^\mu D_\mu - m_e - a^e_\mu \gamma^\mu - b^e_\mu \gamma_5 \gamma^\mu - \frac{1}{2} H^e_{\mu\nu} \sigma^{\mu\nu} + i c^e_{\mu\nu} \gamma^\mu D^\nu + i d^e_{\mu\nu} \gamma_5 \gamma^\mu D^\nu)\psi = 0$$

Lorentz Invariance Violating terms

R.Bluhm, A.Kostelecky, N.Russell,
**Phys. Rev. Lett. 82, 2254 (1999)**

- a & b have energy dimensions (→ absolute comparisons are important)

- No quantitative prediction

# H and $\bar{H}$ spectroscopy

Benefits: - In principle direct experimental test (no model is required)

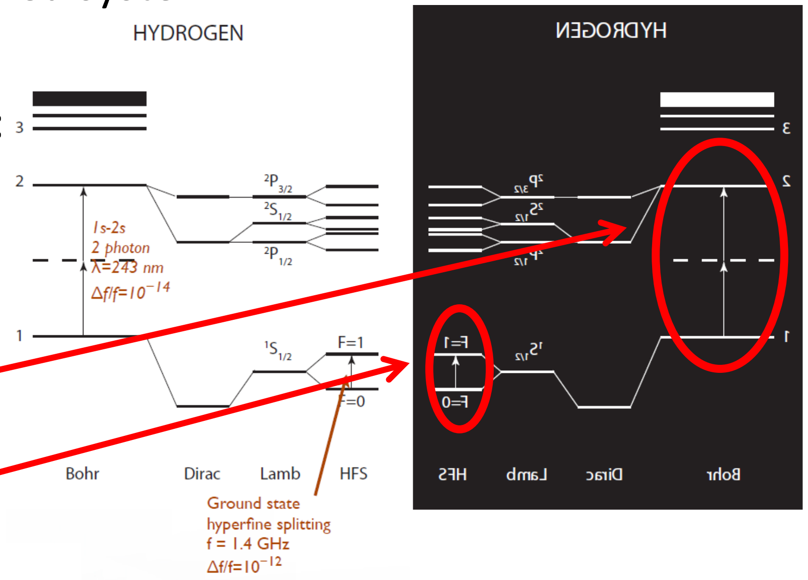
- Hydrogen is one of the best measured system

Today only at CERN-AD (since 2021 with ELENA):

ASACUSA, ALPHA

2 plans:

- measurements:
  - Antihydrogen 1S-2S
  - Antihydrogen GS-HFS




- methods:
  - Trapping antihydrogen <-- done (ALPHA. 1000 s)
  - Antihydrogen beam <-- done (ASACUSA)

(very recent) results from ALPHA

GS-HFS rel. precision 4 x $10^{-4}$ *Nature (2017)*

1S–2P Lyman-α rel. precision 5 x $10^{-8}$ *Nature (2018)*

1S–2S rel. precision 2 × $10^{-12}$ *Nature (2018)*

# WEP and Antimatter

The **Weak Equivalence Principle** of general relativity (UFF - Universality of Free Fall):

**"two bodies of different compositions and/or mass fall at the same rate in a gravitational field "**

Newtonian version

## With matter

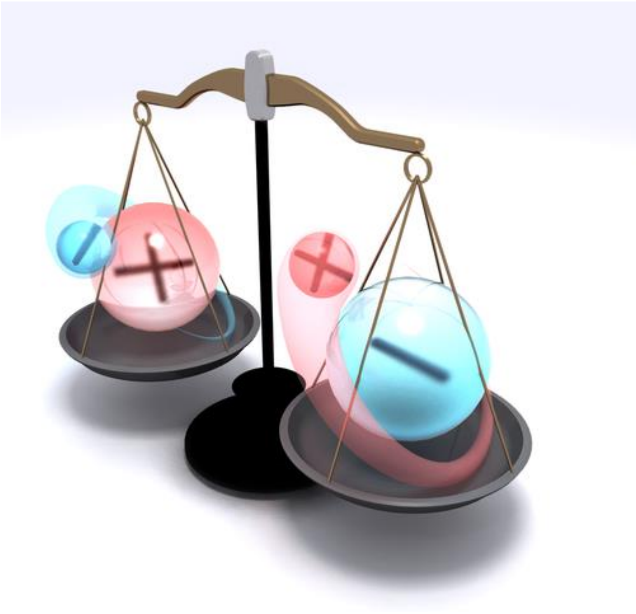
Many tests

On Earth with torsion balances: relative precision ~ $10^{-13}$

In Space (MICROSCOPE mission): relative precision ~ $10^{-14}$

*Class. Quantum Grav. 2019*

# WEP and Antimatter



## With antimatter

- From General relativity no difference expected
- Quantum gravity theories may allow differences
- From SME: WEP violation results from Lorentz and CPT violation

  - No precise direct measurements

PS200 (LEAR-CERN) with p and $\bar{p}$: g never measured

ALPHA-g with $\bar{H}$ : $-65 < \frac{m_g}{m_i} < 110$

# AEgIS

## Antihydrogen Experiment: Gravity, Interferometry and Spectroscopy

## AEgIS collaboration

16 Institutions    35 Researchers

Funded by INFN since 2010

INFN contact person: Roberto Brusa (Tn)

The scientific coordinator of the experiment is an INFN member

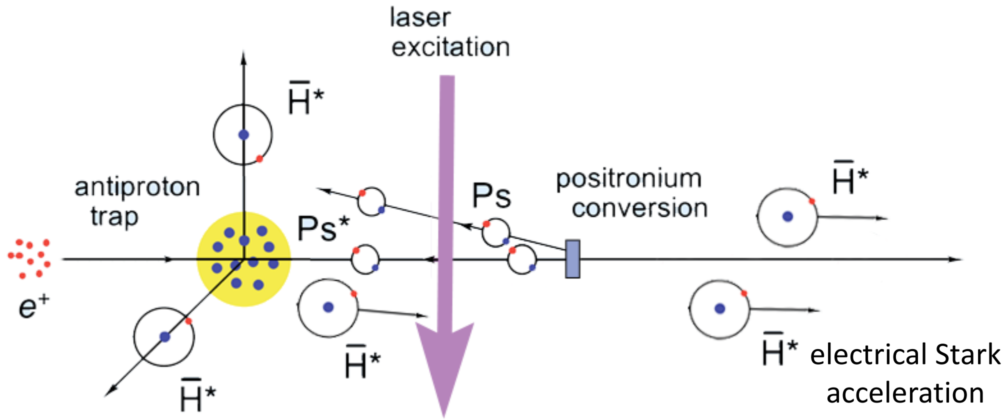
INFN groups have responsabilities on:

- Antiprotons traps
- Positron beam
- Positronium formation
- Lasers for Ps excitation
- External Detector

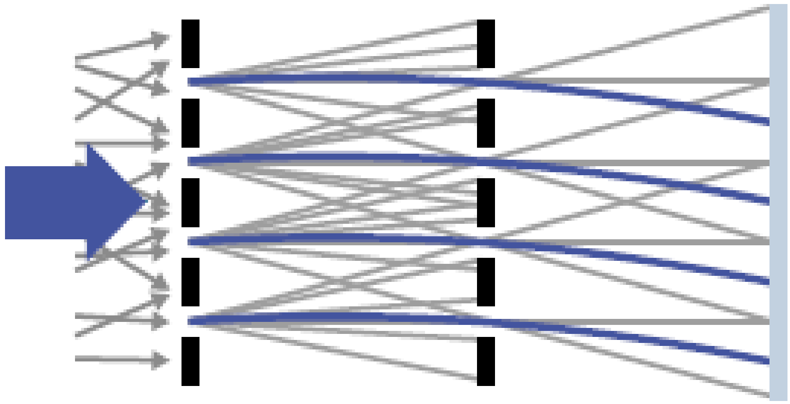
# AEgIS : Overview of the experiment

Physical goal: measurement of the gravitational interaction between matter and antimatter

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




**Atomic beam**



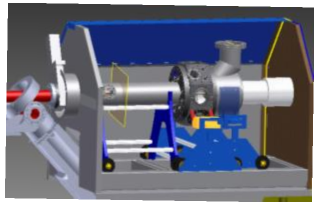
**Pulsed production**

**Beam formation**

**Gravity measurement**

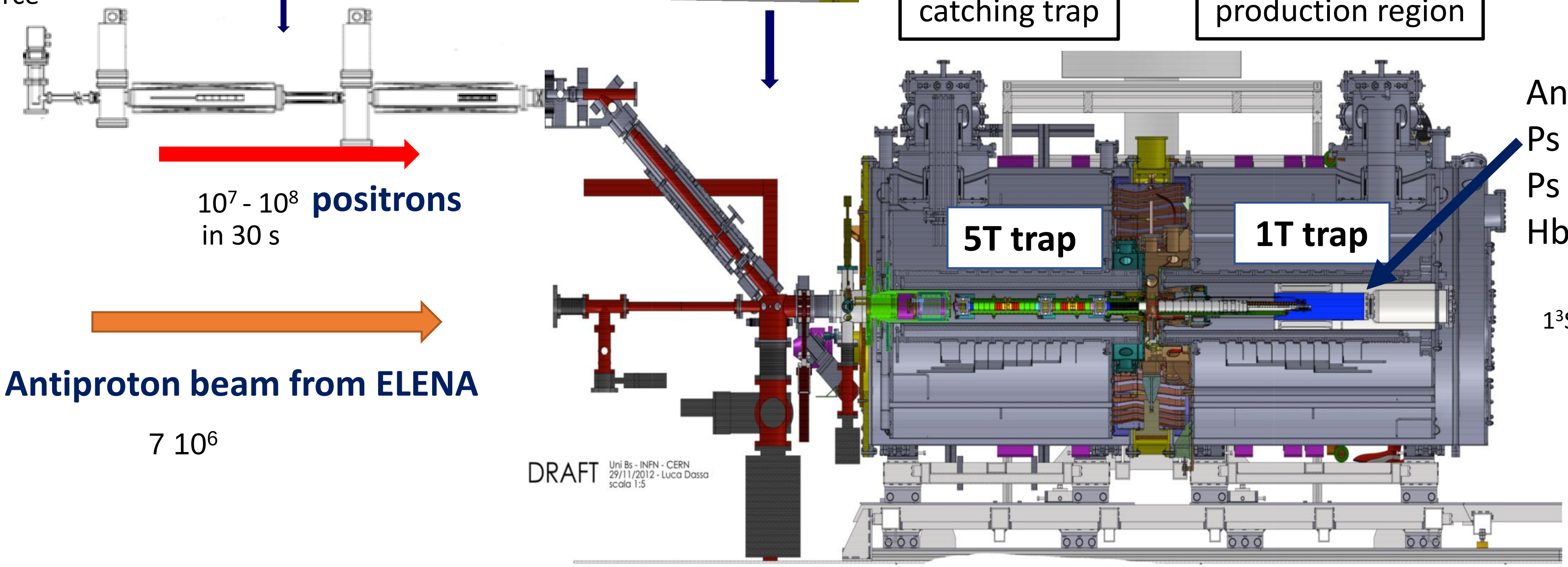
# AEgIS apparatus

Chamber for
Ps R&D



e+ bunched beam

$^{22}$Na $e^+$
source




antiproton
catching trap

Antihydrogen
production region

5T trap

1T trap

Antiproton trapping
Ps cooling & converter
Ps excitation
Hbar formation

Ps is laser excited:
$1^3S \rightarrow 3^3P \rightarrow$ Rydberg (n 15-17)

$10^7$ - $10^8$ **positrons**
in 30 s

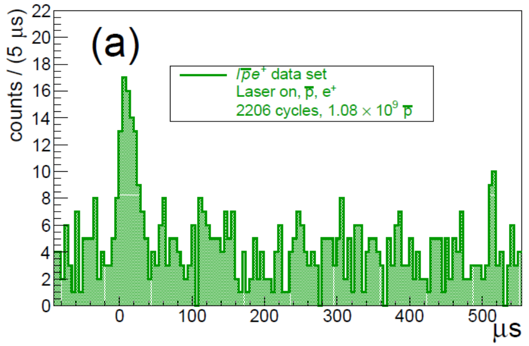
**Antiproton beam from ELENA**

7 $10^6$

Antiprotons
cooled by e-

# AEgIS results

- Trapping and storage $\bar{p}$
- Pulsed Ps formation into vacuum
- Excitation of Ps in Rydberg states
- **Pulsed production of $\bar{H}$ in Rydberg states $(\bar{H}^*)$**




**Pulsed production of antihydrogen 2018**
**Communication Physics-Nature- (2021)**

- **2021 $\bar{p}$ run:**
  - many modifications to the apparatus (tested)
  - automated control system commissioned
  - e+ beam performances recovered after re-mounting
  - antiproton degrading and trapping validated

## Steps towards $\bar{H}$ free fall measurement

- Increase of pulsed production of $\bar{H}^*$
- $\bar{H}^*$ Stark acceleration
- Ballistic beam of $\bar{H}^*$
- characterization of the $\bar{H}^*$ beam
- Deflectometry (moiré deflectometer)
- $\bar{H}^*$ de-excitation in $\bar{H}$
- Measure of $\bar{H}$ free fall

# Expected Results (2022-2025)

AEgIS

| AEgIS ACTIVITIES | 2022 | | 2023 | | 2024 | | 2025 | |
|---|---|---|---|---|---|---|---|---|
| Nominal catching pbar from ELENA | X | | | | | | | |
| Cooling and trapping pbar in 1T | | X | | | | | | |
| Formation Hbar | | | X | | | | | |
| Beam formation of Hbar in Rydberg state | | | | X | | | | |
| Characterization of Hbar in Rydberg states | | | | X | | | | |
| Increasing number of Hbar | | | | | X | | | |
| Study of inertial sensing scheme for Rydberg Hbar | X | X | X | X | | | | |
| Moirè – Mach Zehnder deflectometer construction | | | | X | X | | | |
| Testing Moirè – Mach Zehnder deflectometer: Hbar interaction with grids | | | | | | X | | |
| Gravity test | | | | | | | X | X |
| Implementation of position sensitive detector for Hbar | | | X | X | | | | |
| Test of Positronium cooling | X | | X | | | | | |

N.B. LS3 will start on 2026

# ALPHA

## **A**ntihydrogen **L**aser **Ph**ysics **A**pparatus

17 institutes, ~ 50 researchers

+ (since 2022)

INFN contact person: Germano Bonomi (Bs-Pv)

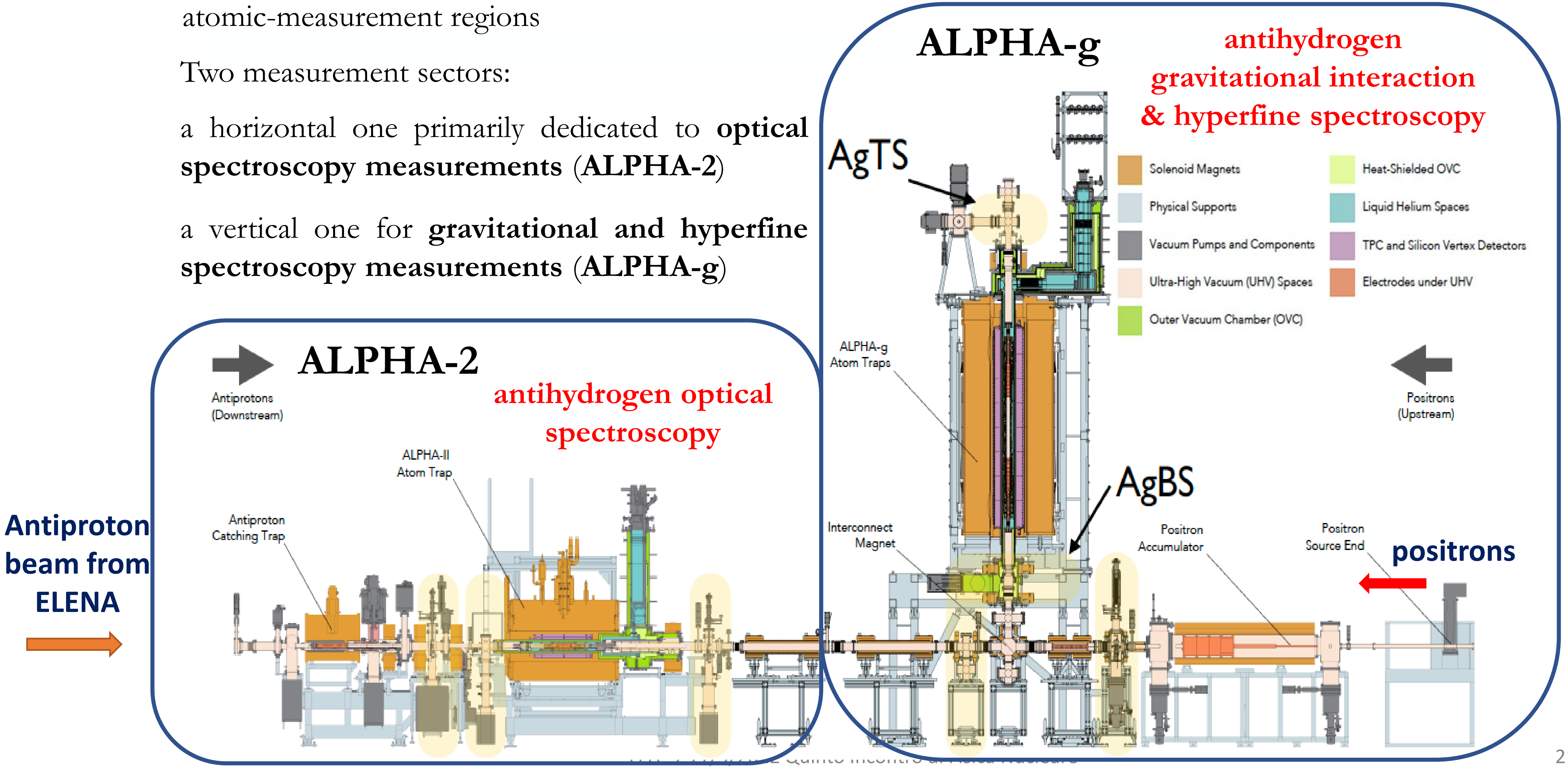
# ALPHA apparatus

ALPHA adopted a modular design, in which the antiproton-catching Penning trap is separated from the atomic-measurement regions

Two measurement sectors:

a horizontal one primarily dedicated to **optical spectroscopy measurements** (**ALPHA-2**)

a vertical one for **gravitational and hyperfine spectroscopy measurements** (**ALPHA-g**)



# ALPHA results

## SOME RESULTS ON ANTIHYDROGEN CONFINEMENT AND SPECTROSCOPY

o) "*Trapped antihydrogen*" - Nature 468.7324 (2010)
o) "*Confinement of antihydrogen for 1,000 seconds*" - Nature Physics 7.7 (2011)
o) "*Resonant quantum transitions in trapped antihydrogen atoms*" - Nature 483.7390 (2012)
o) "*Observation of the hyperfine spectrum of antihydrogen*" - Nature 548.7665 (2017) rel. precision $4 \times 10^{-4}$
o) "*Observation of the 1S-2S transition in trapped antihydrogen*" - Nature 541.7638 (2017)
o) "*Characterization of the 1S-2S transition in antihydrogen*" - Nature 557.71 (2018) rel. precision $2 \times 10^{-12}$ (in H: $4.2 \times 10^{-15}$)
o) "*Observation of the 1S–2P Lyman-a transition in antihydrogen*" - Nature 561.7722 (2018) rel. precision $5 \times 10^{-8}$
o) "*Investigation of the fine structure of antihydrogen*" – Nature 578.375 (2020)
o) "*Laser cooling of antihydrogen atoms*" – Nature 592.35 (2021)

## SHORT-MID TERM GOALS

- The highest priority for the next years will be **the first experiments on antimatter gravity**
  In particular: at first to determine the **sign of the gravitational force**; then measure the **intensity**
- Improvement of **a factor of 10 in 1S-2S precision** (thanks to laser cooling and metrology)

# Expected Results (2022-2025)

ALPHA

| ALPHA | 2022 | | 2023 | | 2024 | | 2025 | |
|---|---|---|---|---|---|---|---|---|
| ELENA beamline and pbar trapping commissioning | X | | | | | | | |
| First measurement of matter-antimatter gravitational interaction (sign of g) | X | X | X | X | | | | |
| Metrology upgrades (hydrogen maser and cesium fountain clock) to achieve 10^{-13} absolute frequency accuracy | X | X | X | X | X | X | X | X |
| Improvements of the Lyman-alpha laser cooling (to achieve antiproton temperatures below 20 mK) | | | X | X | X | X | X | X |
| Precise measurements of matter-antimatter gravitational interaction (up to 1% accuracy) | | | X | X | X | X | | |
| Improvement of the 1S-2S transition measurement (x10) | | | X | X | X | X | | |
| Measurement of the d to c hyperfine [NMR - nuclear magnetic resonance] transition | | | | | X | X | | |
| Improvement of the 1S-2P transition measurement | | | | | X | X | | |

N.B. LS3 will start on 2026

# ASACUSA

## Atomic Spectroscopy And Collisions Using Slow Antiprotons

INFN contact person: Luca Venturelli (Bs-Pv)

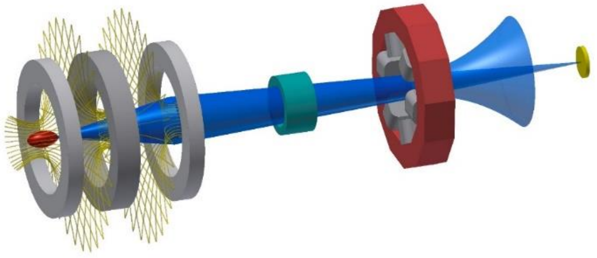
15 Institutions 40 Researchers

- antiprotonic helium atoms with laser spectroscopy to test CPT
- antihydrogen ground-state hyperfine structure to test CPT.
- atomic and nuclear collision cross sections of antiprotons at low energies.

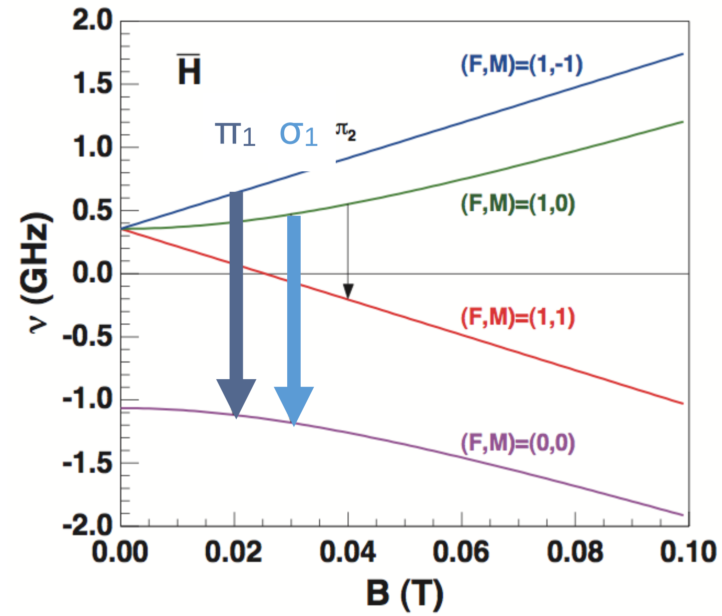
Funded by INFN since 2005

# ASACUSA in-beam HFS spectroscopy

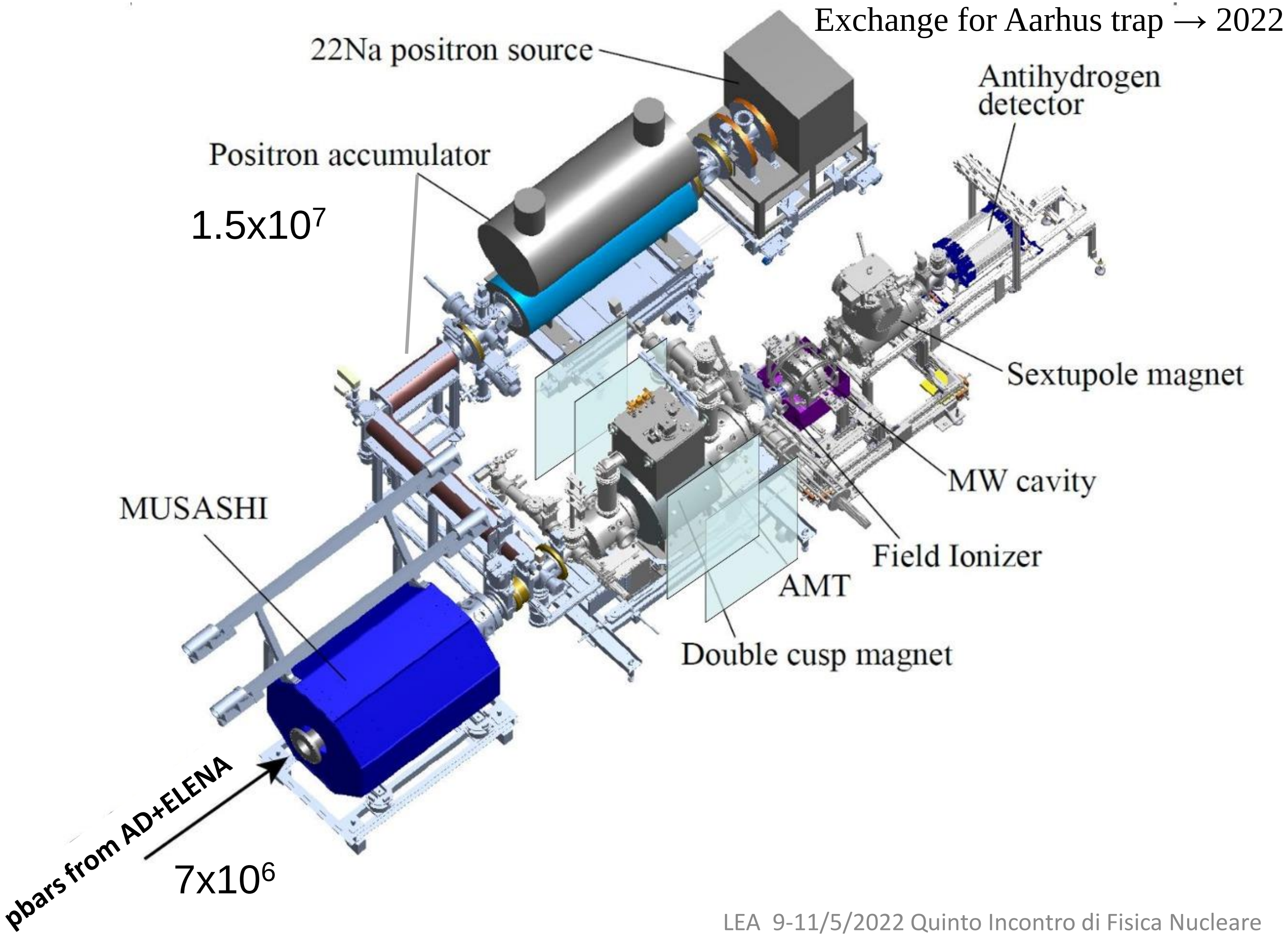
- Goal
  - In-beam measurement of ground-state hyperfine structure of antihydrogen to ppm-level and below

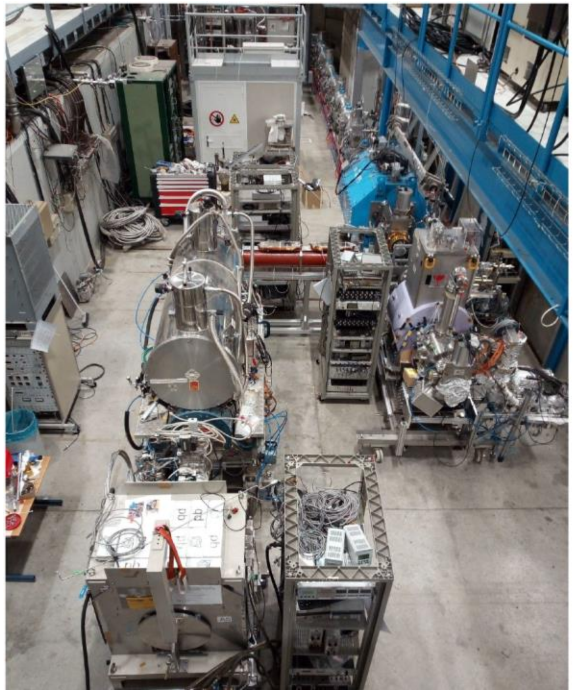


- Method
  - Produce polarized Hbar beam
  - Measure $\sigma_1$ (and/or $\pi_1$) at several B's, extrapolate to B=0
  - Achievable precision $10^{-6}$ for T~50 K
  - > 100 Hbars/s in 1S state into 4 $\pi$ needed
  - Event rate 1/min ; bkg from cosmics, upstream annihilations



# ASACUSA Setup



# ASACUSA results and improvements

## Antihydrogen

Main results of ASACUSA on antihydrogen

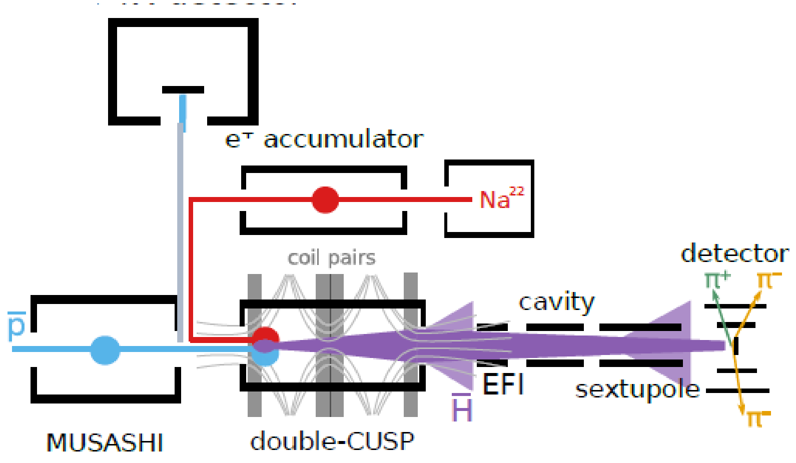
- **First antihydrogen** formed **in a cusp trap** *(PRL 2010)*
- **First antihydrogen beam** *(Nature Comm. 2014)*
- Best hyperfine spectroscopy with hydrogen beam (2.7 $10^{-9}$) *(Nature Comm. 2017)*
- 40 x $10^6$ **particles cooled to T<30 K** *(2021 to be published)*

Needed:

- Increase the antihydrogen production rate and lowering the quantum states of antihydrogen

## Parasitic experiments

planning to create a secondary parasitic beam line to have a **slow extraction of low-energy antiprotons** from MUSASHI.
The continuous antiproton beam will allow to perform several other experiments (fragmentation studies of antiproton-nucleus annihilations, measurement of the cross sections of Pontecorvo reactions, antiproton interferomery, ...).



# Expected Results (2022-2025)

ASACUSA

Antihydrogen experiment

Nuclear physics

| | 2022 | | 2023 | | 2024 | | 2025 | |
|---|---|---|---|---|---|---|---|---|
| Matter experiments (pbar & e+) | X | X | X | X | X | X | X | X |
| New e+ source | X | X | | | | | | |
| Antihydrogen beam interaction with MW | | X | X | X | | | | |
| Antihydrogen GS-HFS measurement ( 1ppm resolution) | | | X | X | X | X | X | X |
| Installation of parasitic beamline | | X | X | X | | | | |
| Pbar-nuclei annihilation products in 4 $\pi$ sr detector | | | X | X | X | X | | |
| Building new detector for Pontecorvo measurement | | | | | X | X | X | X |

N.B. LS3 will start on 2026

# PsICO and QUPLAS

# Physics motivation for e+ and Ps studies

Fundamental Physics with positrons/electrons and the most fundamental atom: Positronium

| | |
|---|---|
| 0 | |
| | Ps |
| 0.0011 | |

- Historically: tests of higher-order radiative QED correction (mass, lifetime…)

- Studying CPT (LIV) and the WEP physical with fundamental fermions, implying a direct violation of the
- Standard Model at the level of the Dirac terms:

$$(i\gamma^{\mu}\partial_{\mu} - eA_{\mu}\gamma^{\mu} - a_{\mu}\gamma^{\mu} - b_{\mu}\gamma_{5}\gamma^{\mu} - m)\psi = 0,$$

- Sensitive to different operators of the Standard Model Extension than hadronic systems.

# PsICO

## Positronium Interferometry and Correlation Observations

INFN contact person:
Sebastiamo Mariazzi (Tn)

INFN/TIFPA
INFN-Milano

Istituto Nazionale di Fisica Nucleare

Trento Institute for Fundamental Physics and Applications

universität wien

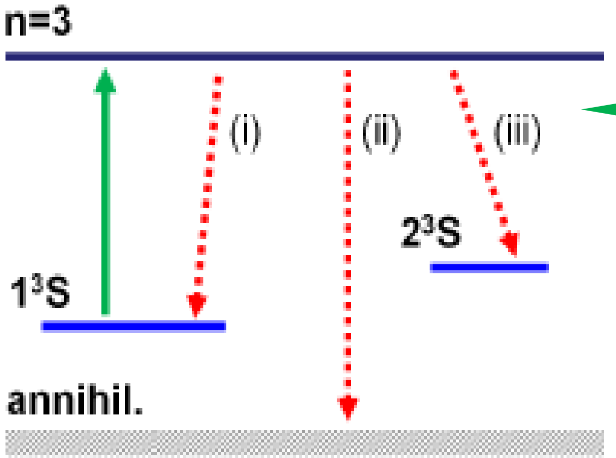
JAGIELLONIAN UNIVERSITY IN KRAKÓW

**Main goals of PsICO:**

1) inertial sensing measurements with the purely leptonic system

2) entanglement of the 3γ coming from the annihilation of Ps prepared in selected quantum states

**Obtained results**




Pulsed production of monochromatic **positronium in the metastable state** via laser excitation.

PHYSICAL REVIEW A **94**, 012507 (2016)

**Laser excitation of the $n = 3$ level of positronium for antihydrogen production**

PHYSICAL REVIEW A **98**, 013402 (2018)

**Producing long-lived $2\,^3S$ positronium via $3\,^3P$ laser excitation in magnetic and electric fields**

PHYSICAL REVIEW A **99**, 033405 (2019)

**Velocity-selected production of $2\,^3S$ metastable positronium**

PHYSICAL REVIEW A **100**, 063414 (2019)

**Efficient $2\,^3S$ positronium production by stimulated decay from the $3\,^3P$ level**

# Main goals

## 1) inertial sensing measurements with the purely leptonic system

- Optimization of the already demonstrated $2^3S$ Ps beam

Vol. 137 (2020) *ACTA PHYSICA POLONICA A*

**Techniques for Production and Detection of $2^3S$ Positronium**

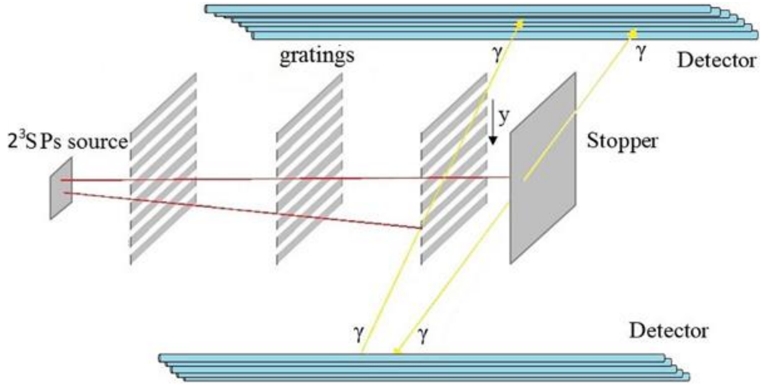
- Experiments of deflectometry and interferometry to measure forces, including gravity, exerted on a pulsed monochromatic metastable positronium beam.

Eur. Phys. J. D (2020) 74: 79
https://doi.org/10.1140/epjd/e2020-100585-8

THE EUROPEAN PHYSICAL JOURNAL D

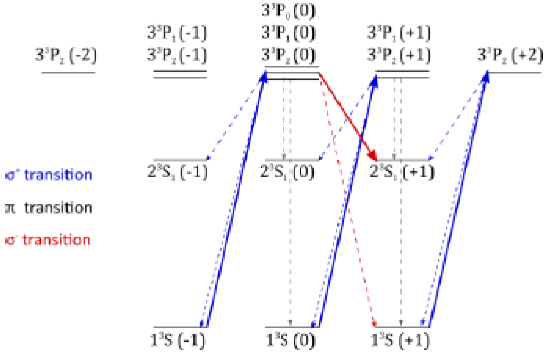
Regular Article

**Toward inertial sensing with a $2^3S$ positronium beam**

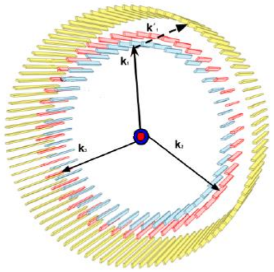



## 2) entanglement of the 3γ coming from the annihilation of Ps prepared in selected quantum states

Production of pulses of $2^3S$ with defined magnetic quantum number via $1^3S$-$3^3P$-$2^3S$ two-step laser excitation with polarized laser pulses.




Study of the entanglement of the 3γ as a function of the Ps quantum numbers.



Measurement of the polarization of the 3γ generated by the $2^3S$ Ps annihilation.

(the polarization is mainly perpendicular to the plane containing the momenta of the primary gamma ray and of the Compton scattered)

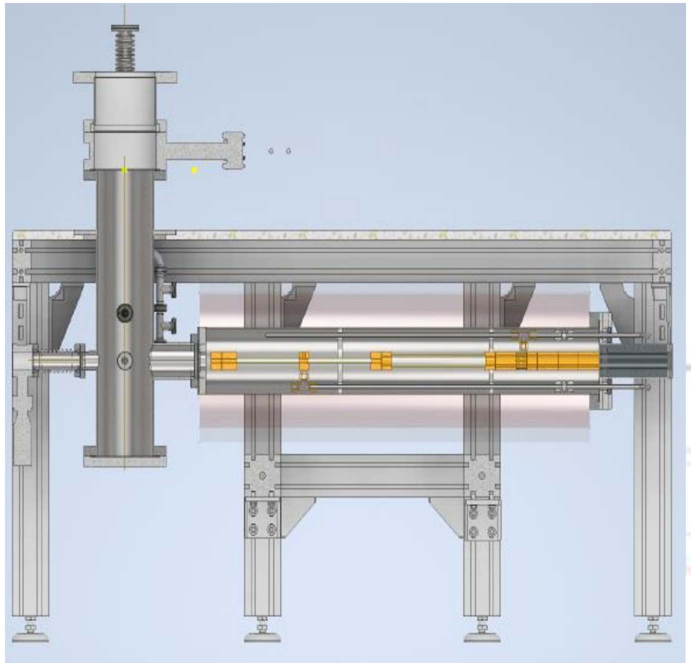
Expected impacts: - Transport of quantum information; - Polarization surveys of gamma emitters in astrophysics; - PET application; - Fundamental studies on C,P,T or CP or CPT violations

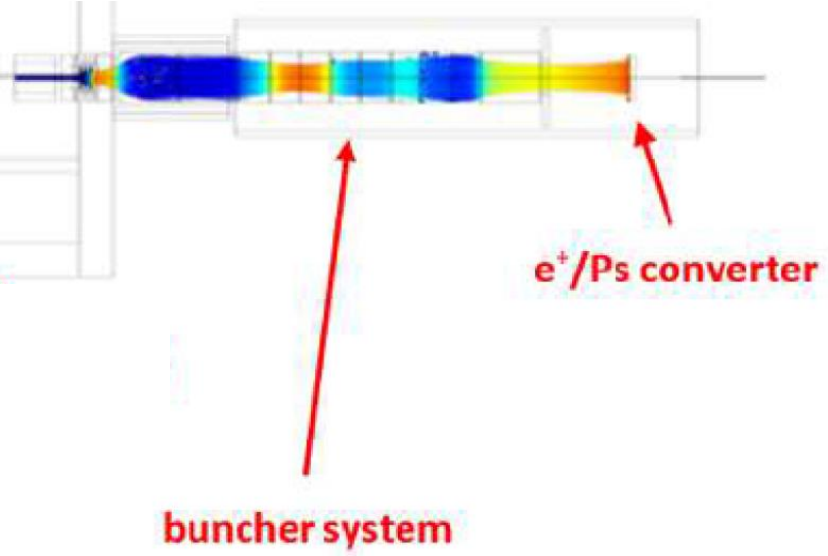
# APPARATUS

@ TIFPA-UniTN

*For both the goals*

## New pulsed e+ beam






Na²² Source+moderator → $Na^{22}$ Source+moderator

**under commissioning**

Surko trap

**Designed- to be built**

# Expected Results (2022-2025)

PsICO

| | 2022 | | 2023 | | 2024 | | 2025 | |
|---|---|---|---|---|---|---|---|---|
| Construction and assembly positron Surko trap | X | X | | | | | | |
| Installation laser system for n=3 and IR | | X | X | | | | | |
| Testing positron bunched beam, Ps formation and Ps excitation to 2^3S and Rydberg | | | X | X | | | | |
| Development of the detector for measurement of gamma ray polarization | X | X | X | X | | | | |
| Measurement of polarization of Ps annihilation gammas | | | | | X | X | | |
| Test of entanglement of gamma polarization | | | | | | X | X | X |
| Tests of transmission of material gratings with 2^3S and Rydberg Ps beams | | | | X | X | X | | |
| Development of a classical deflectometer for 2^3S Ps | | | | | X | X | | |
| Inertial sensing measurement of magnetic or laser dipole forces on 2^3S Ps | | | | | | | X | X |

# QUPLAS

## (QUantum interferometry and gravitation with Positrons and LASers)

INFN contact person: Marco Giammarchi (Mi)

- Started in 2015: a phased approach to LIV, CPT and WEP studies with e-, e+, Ps
- Based on a CONTINUOUS BEAM, interferometers and high-resolution detectors
- Home of the experiment: Positron Lab of the Politecnico di Milano in Como:

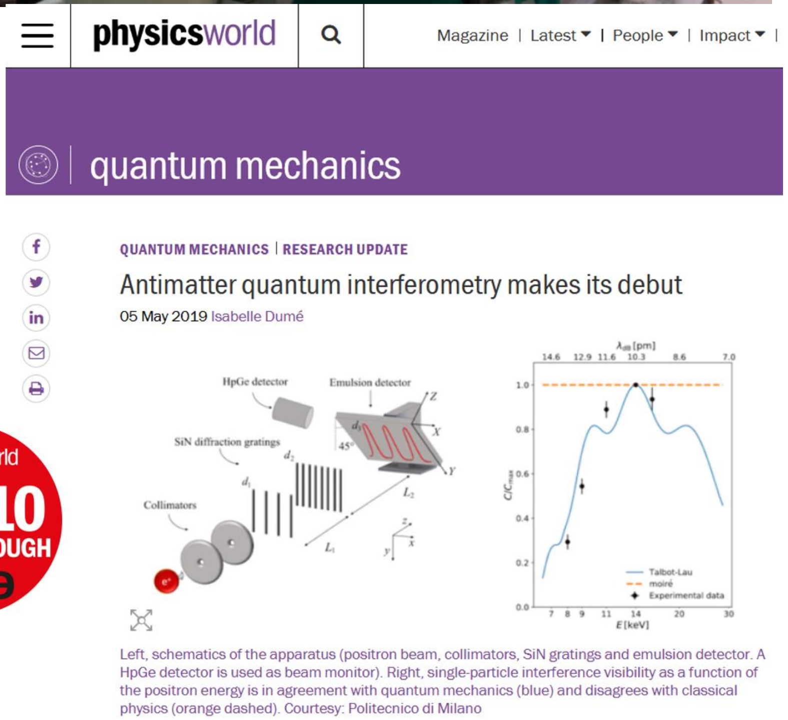

QUPLAS is a continuous SINGLE-PARTICLE interference experiment

- QUPLAS-0: Positron interferometry
- QUPLAS-I: Positronium Interferometry
- QUPLAS-II: Positronium Gravitation

QUPLAS-0 is the antimatter version of the Merli-Missiroli-Pozzi experiment

**First demonstration of Antimatter Quantum Interferometry**

S. Sala, A. Ariga, A. Ereditato, R. Ferragut, M. Giammarchi, M. Leone, C. Pistillo, P. Scampoli
**Science Advances 5 eaav7610 (2019) doi: 10.1126/sciadv.aav7610**


physicsworld | Magazine | Latest | People | Impact |

quantum mechanics

QUANTUM MECHANICS | RESEARCH UPDATE

Antimatter quantum interferometry makes its debut

05 May 2019 Isabelle Dumé

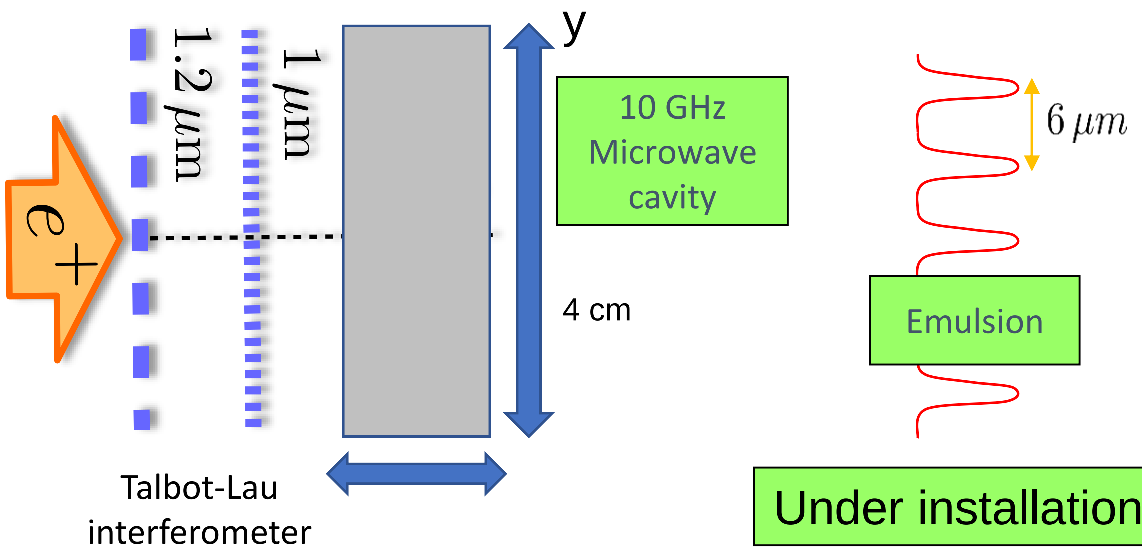


Left, schematics of the apparatus (positron beam, collimators, SiN gratings and emulsion detector. A HpGe detector is used as beam monitor). Right, single-particle interference visibility as a function of the positron energy is in agreement with quantum mechanics (blue) and disagrees with classical physics (orange dashed). Courtesy: Politecnico di Milano

# Application of Quplas-0

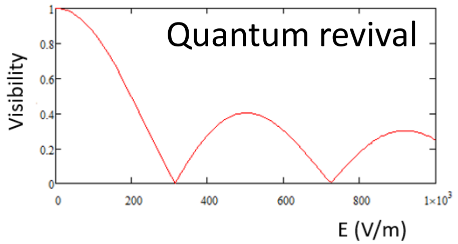
## The Microwave experiment

- Technique: use the «usual» Quplas configuration and add a **microwave cavity** after the second grating.
- **Quantum decoherence** study
- Measure the (single) Fermion phase shift due to e.m. interaction



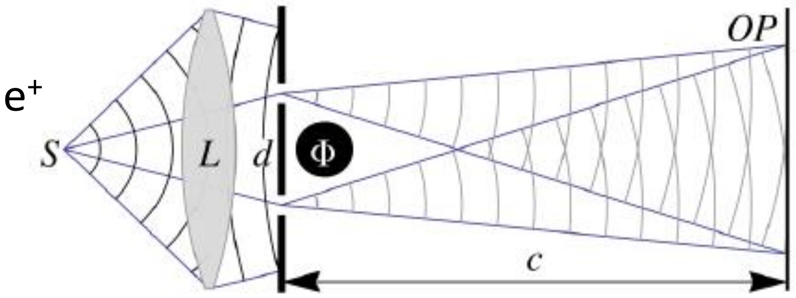

Under installation now

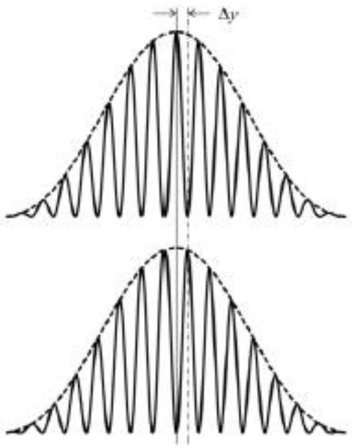
Prediction




## The Aharonov-Bohm experiment

- Pure quantum-mechanical effect
- Goal: first demonstration of the AB effect with a particle different from $e^-$

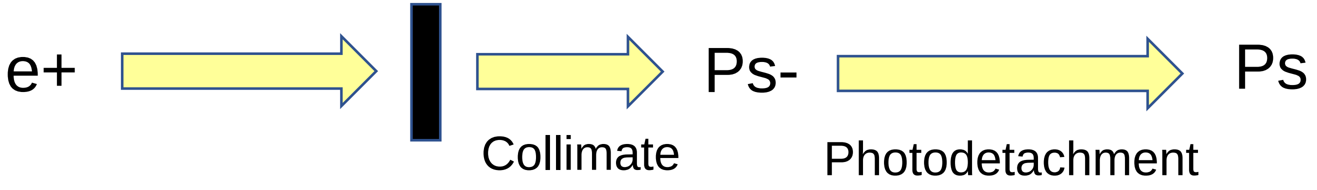


# QUPLAS-I ( and II) design

QUPLAS-I: Positronium Interferometry
QUPLAS-II: Positronium Gravitation

Ps- production at Como and Laser studies in Florence

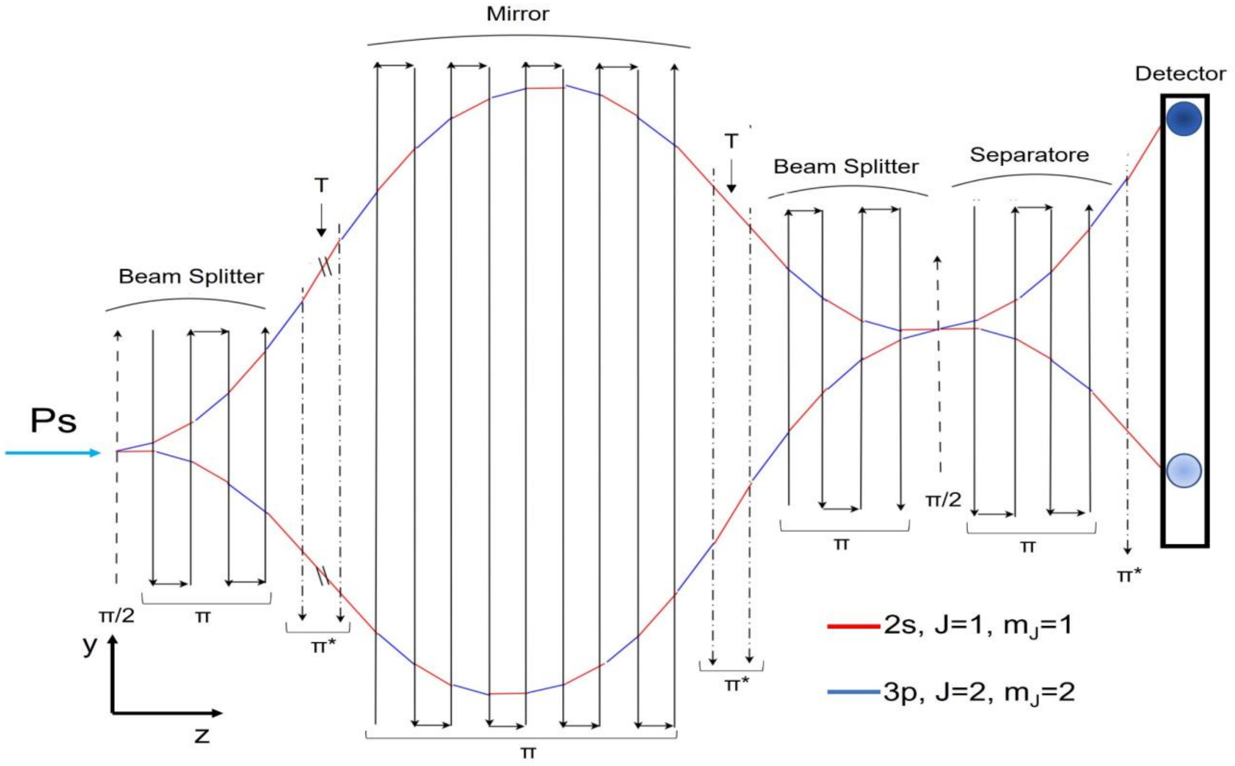



1) Ps- e photodetachement study with a simplified chamber at L-NESS Como
   Goal: demonstrate Ps- production

2) Photodetachement cavity under study in Florence.

News of the design: this Mach-Zehnder laser-cavity would work for FAST positronium, making the gravitational study possible without the cooling

Know-how from MAGIA



# Expected Results (2022-2025)

QUPLAS

| | 2022 | | 2023 | | 2024 | | 2025 | |
|---|---|---|---|---|---|---|---|---|
| Quantum Revival with Microwaves | X | X | X | | | | | |
| Aharonov-Bohm experiment | | | | X | X | X | | |
| QUPLAS-I Ps- Beam formation in Como | X | X | X | | | | | |
| Photodetachment cavity operational in Florence | X | X | X | | | | | |
| Integration in Como (Photodetachment) | | | | X | X | | | |
| QUPLAS-I Quantum Interferometry | | | | | X | X | | |
| QUPLAS-II Slow Ps Beam formation | | | | | | | X | X |

# LEA EXPERIMENTS

The 5 experiments have different technologies and methodologies

- **AEgIS** and **ASACUSA** use $\bar{H}$ beams
- **ALPHA** captures $\bar{H}$
- **PsICO** uses pulsed beams of e+ and Ps
- **QUPLAS** uses continuous beams of e+ and Ps

*but many synergies are possible …*

# LEA  SYNERGIES

QUPLAS expertise on interferometry → **antiproton interferometry** in ASACUSA

Mi/Co group from QUPLAS has designed and built the **new positron accumulator** for ASACUSA

AEgIS-ASACUSA cooperation to study rapid **de-excitation of antihydrogen** Rydberg atoms

**e+/Ps converter** studied by AEgIS can be shared with other groups

**Optical gratings** used by QUPLAS can be shared with other groups

AEgIS-QUPLAS cooperation for using **light grids** for interferometry and deflectometry

**Virtual Monte Carlo** developed by ALPHA can be shared with other groups

**Machine learning** techniques can be shared between ASACUSA and ALPHA

# CONCLUSIONS

- the presented research activities are of increasing interest *(CERN and institutes investments, more researchers, publications on high IF journals, …)*
- the 5 experiments are underway and have already produced significant results
- the union of the 5 experiments under a single INFN project allows to increase the effectiveness of the activities by increasing the possible synergies