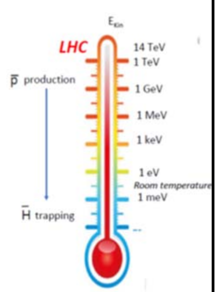
Nuova proposta:
Low Energy Antimatter (LEA)

Luca Venturelli - Università di Brescia & INFN Pavia
on behalf of the LEA collaboration

1

Low Energy Antimatter (LEA)

45 researchers



Letter of Intent

The LEA Collaboration

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2

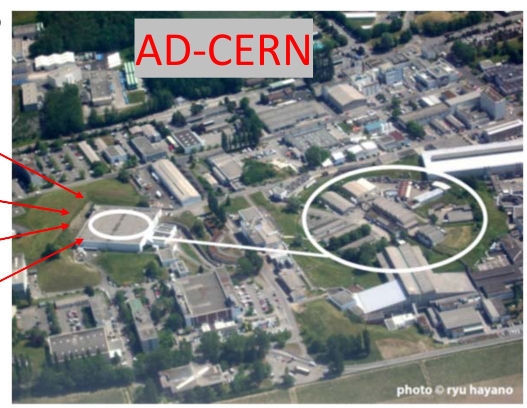
PROPOSAL

The LEA collaboration proposes to group the following projects in one INFN project

- 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 PROJECTS

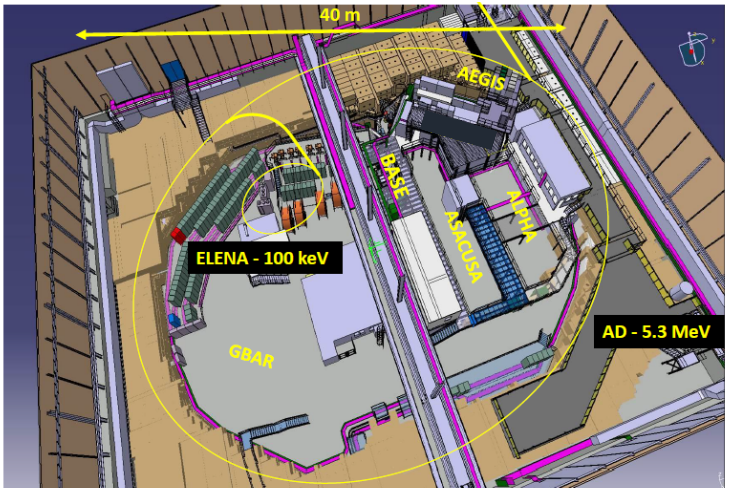
- AEgIS $\bar{p}$ e+ Ps $\bar{H}$
- ALPHA $\bar{p}$ e+ $\bar{H}$
- ASACUSA $\bar{p}$ e+ $\bar{H}$
- PsICO e+ Ps
- QUPLAS e+ Ps



TIFPA-TN

LNESS-CO

Antiproton Decelerator (AD) & ELENA @ CERN



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

AD: 5.3 MeV

ELENA: 5.3 MeV → 100 keV

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

- 5 (+1) 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 operation from 2018 GBAR; 2021 (after LS2) full operation

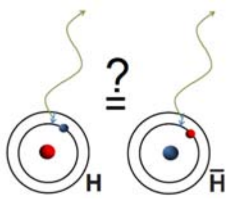
ADVANTAGES: ➢ x 10-100 $\bar{p}$ trapped per experiment ➢ 4 experiments run in parallel (24h/day)

PHYSICS MOTIVATIONS

Why study antihydrogen?

1) Precise matter/antimatter comparison

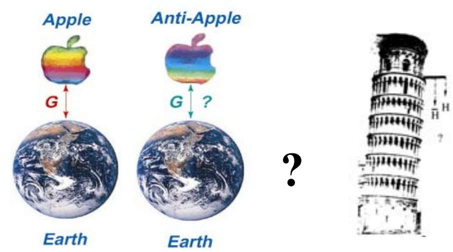
→ test of CPT symmetry



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:

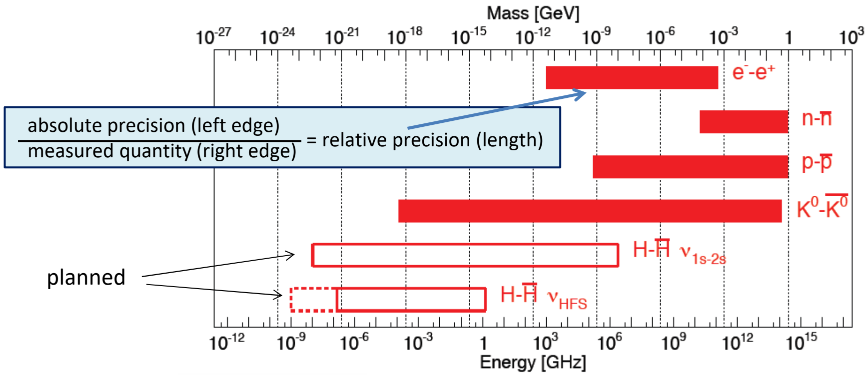
- particle/antiparticle: equal mass, lifetime; equal and opposite charge and magnetic moment
- **atom/antiatom: identical energy levels**

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



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

9

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

Modified Dirac equation

CPT Violating terms

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

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

Lorentz Invariance Violating terms

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

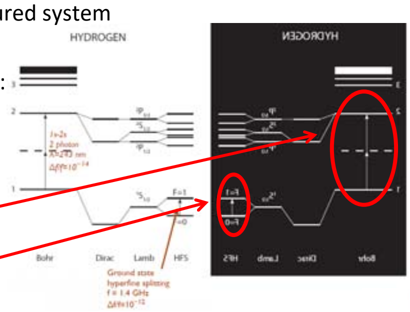
- No quantitative prediction

10

H and $\bar{H}$ spectroscopy

Benefits: - 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)*

11

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

12

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

13

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.

14

LEA PROJECTS

15

AEgIS

Antihydrogen Experiment: Gravity, Interferometry and Spectroscopy

AEgIS collaboration

16 Institutions 35 Researchers

Funded by INFN since 2010

The scientific coordinator of the experiment is an INFN member

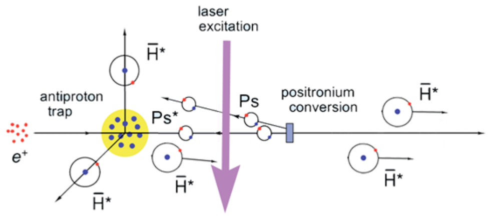
INFN groups have responsabilities on:

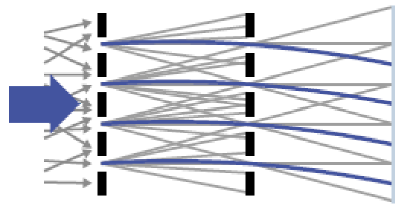
- Antiprotons traps
- Positron beam
- Positronium formation
- Lasers for Ps excitation
- External Detector

16

AEgIS : Overview of the experiment

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

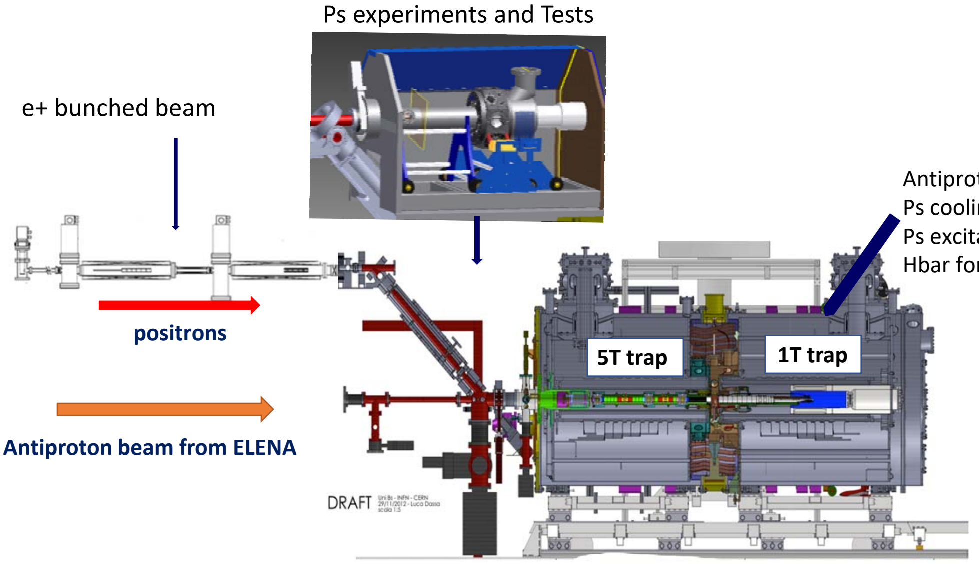




Pulsed production **Beam formation** **Gravity measurement**

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

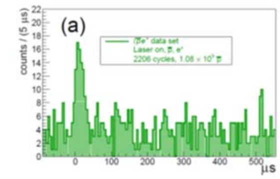
AEgIS apparatus



AEgIS results

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

Pulsed production of antihydrogen 2018
Communication Physics-Nature- 4, 19 (2021)



Steps towards $\overline{H}$ free fall measurement

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

2020-2021 Upgrade of the apparatus with a new trap configuration – new electronics

Aug.- Nov. 2021 pbar catching

2022 Increase of pulsed production of $\overline{\boldsymbol{H}}^*$
$\overline{\boldsymbol{H}}^*$ Stark acceleration

In parallel Positronium laser cooling will be pursued and studies on $\overline{H}^*$ de excitation carried out

19

ASACUSA

Atomic Spectroscopy And Collisions Using Slow Antiprotons

ASACUSA collaboration

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.

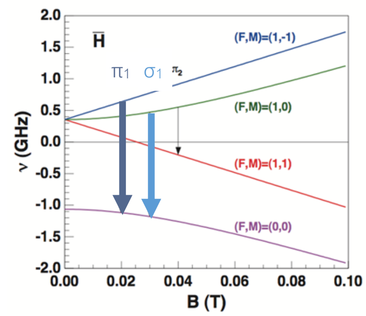
Funded by INFN since 2005

20

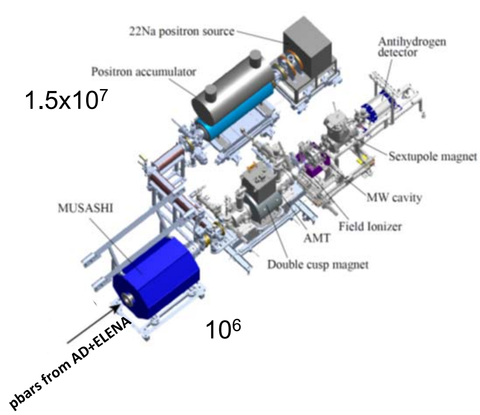
ASACUSA in-beam HFS spectroscopy

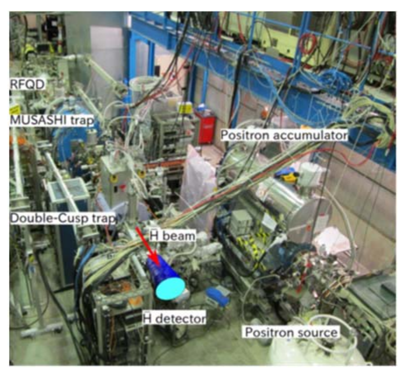
- Goal
  - In-beam measurement of ground-state hyperfine structure of antihydrogen to ppm-level and below

- Method
  - Produce polarized Hbar beam
  - Measure σ_1 (and/or π_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 π needed
  - Event rate 1/min ; bkg from cosmics, upstream annihilations



ASACUSA Setup





ASACUSA results and improvements

Antihydrogen

Main results of ASACUSA on antihydrogen

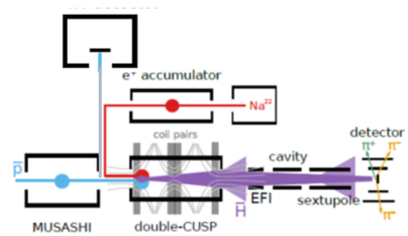
- First antihydrogen formed in a cusp trap *(PRL 2010)*
- First antihydrogen beam *(Nature Comm. 2014)*
- Best hyperfine spectroscopy with hydrogen beam (2.7 10^{-9}) *(Nature Comm. 2017)*

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, ...).



23

ALPHA

17 institutes, ~ 50 researchers

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)
o) "*Observation of the 1S-2S transition in trapped antihydrogen*" - Nature 541.7638 (2017)
o) "*Observation of the 1S–2P Lyman-a transition in antihydrogen*" - Nature 561.7722 (2018)
o) "*Investigation of the fine structure of antihydrogen*" – Nature 578.375 (2020)

24

ALPHA

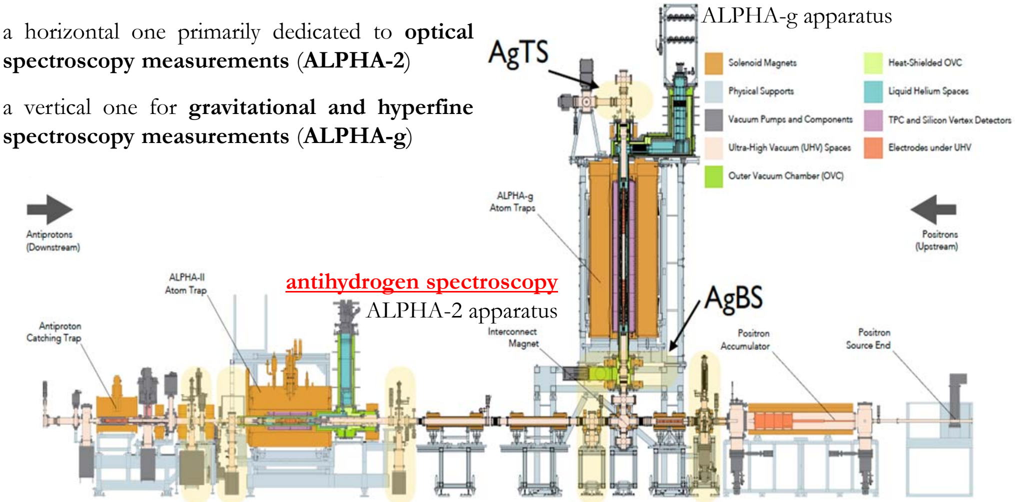
ALPHA adopted a modular design, in which the antiproton-catching Penning trap is separated from the atomic-measurement regions

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**)

(antihydrogen gravitational interaction)
ALPHA-g apparatus



antihydrogen spectroscopy
ALPHA-2 apparatus

ALPHA - short-mid term goals

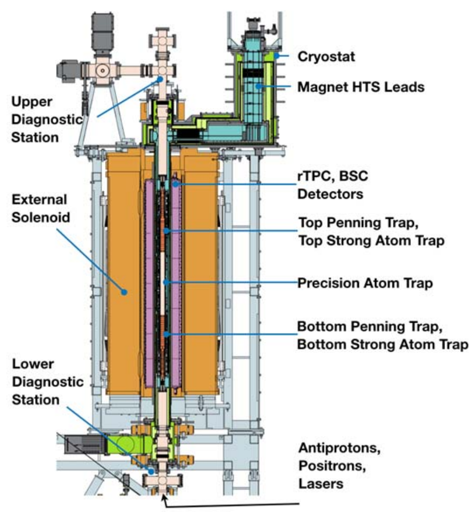
The highest priority for the next years will be **the first experiments on antimatter gravity** (with the ALPHA-g apparatus). In particular:

1) commissioning of the antiproton catching with ELENA

2) the first physics goal is to determine the **sign of the gravitational force**;

3) a more precise experiment is foreseen based on the results of the first measurement.

(antihydrogen gravitational interaction)
ALPHA-g apparatus



ALPHA - short-mid term goals

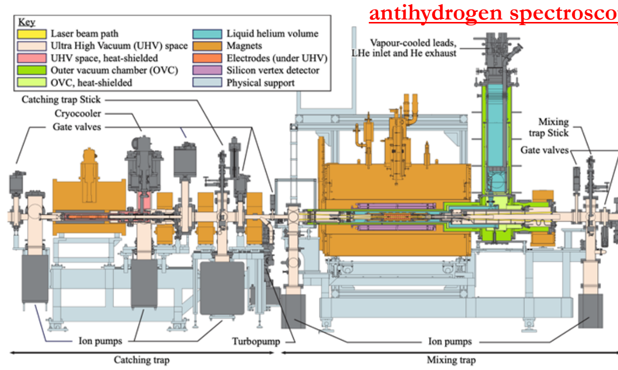
In parallel many improvements and upgrades to the spectroscopy apparatus for more stringent CPT tests. In particular:

o) **upgrade of the optical system** to allow for new laser wavelengths and installation of detectors for fluorescent light inside the cryogenic environment.

o) **new metrology initiatives** for ALPHA spectroscopy will be finalized in the next years. A new laboratory will house a hydrogen maser and the Cs fountain clock that will be used as a primary frequency standard for precision measurements.

ALPHA-2 (=> ALPHA-3) apparatus

antihydrogen spectroscopy



Laser cooling and metrology improvements could give **a factor of 10 improvement in 1S-2S precision** for the measurements in the period 2022-2025.

27

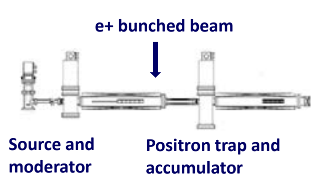
PsICO: Positronium Interferometry and Correlation Observations

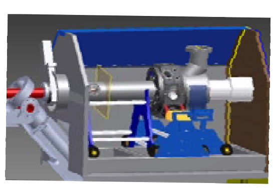
INFN/TIFPA
INFN-Milano

No Common Funds cost

Experimental set-up

AEgIS positron system (CERN)



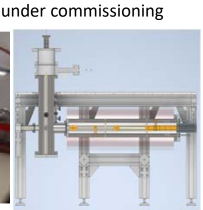


e+ beam at TIFPA-UniTN

continuous e+ beam→

new pulsed e+ beam

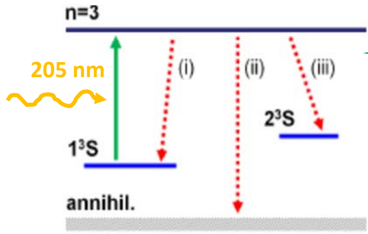
Source and moderator under commissioning



28

PsICO

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 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.

29

Main goals of PsICO 1/2

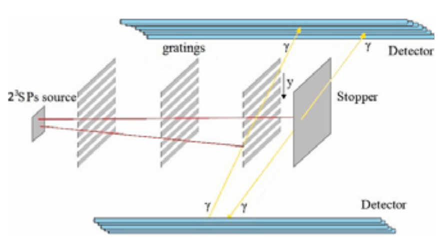
1) inertial sensing measurements with the purely leptonic system

Scientific steps:

- 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
THE EUROPEAN PHYSICAL JOURNAL D
Regular Article
Toward inertial sensing with a 2^3S positronium beam

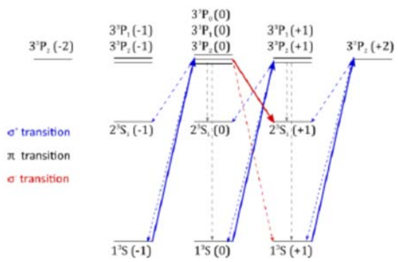
30

Main goals of PsICO 2/2

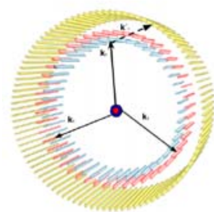
2) entanglement of the 3γ coming from the annihilation of Ps prepared in selected quantum states

Scientific steps:

- 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.



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



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

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

Expected impacts:

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

LEA 11/2/2021 CSN3 INFN 31

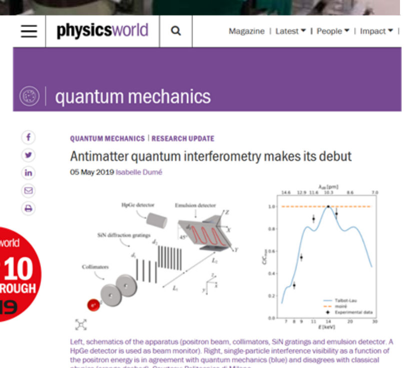
31

QUPLAS
(QUantum interferometry and gravitation with Positrons and LASers)

- Started in 2015: a phased approach to LIV, CPT and WEP studies with e-, e+, Ps
- Founded by the Milano, Como and Bern groups.
- Based on a CONTINUOUS BEAM, interferometers and high-resolution detectors
- Home of the experiment: Positron Lab of the Politecnico di Milano in Como: https://www.positron.fisi.polimi.it/

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

physics world TOP 10 BREAKTHROUGH 2019

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

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32

QUPLAS - short-mid term goals

QUPLAS-0 further physics goals being pursued (spin-offs):

- Radiative decoherence of single antiparticles and the revival effect
  Goal: first demonstration of quantum revival with in single particle mode
  (installation phase)

- Search for the antimatter Aharonov-Bohm Effect.
  Goal: first demonstration of the AB effect with a particle different from e^-
  (advanced design phase)

Funding sources: INFN, UNIMI and the PoliMI (supporting the beamline and paying on-site operational costs and giving priority to QUPLAS)

No Common Funds cost

33

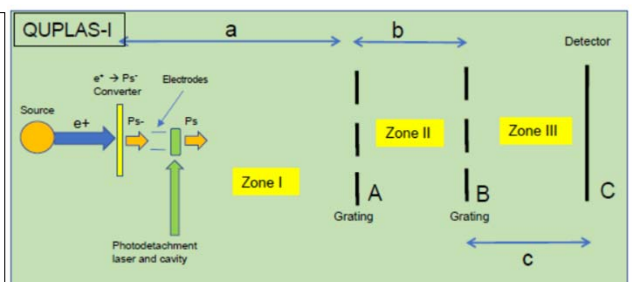
QUPLAS - short-mid term goals

QUPLAS-I: Positronium Interferometry

- A technique for a coherent continuous Ps beam
  - Preparation of a Ps- charged beam (conceptual design done)
  - Ps- photodetachment in an optical cavity (design done)

- A suitable Interferometer (likely in Talbot-Lau mode)
  Material gratings → Optical gratings

- High-resolution detectors being studied
  Two type of detectors being studied



Key elements: reaching a finesse of 40000 for the cavity, needed to operate in the CONTINUOUS beam configuration

N.B.: It will be similar to the cavity needed for QUPLAS-II

QUPLAS-I Schedule :
- Full installation between 2022 and 2023
- Data taking in 2024

Hopefully we'll discuss **QUPLAS-II** in 2025

An enlarged collaboration - QUPLAS Groups:
Como (R. Ferragut), Milano (M. Giammarchi), Brescia-PV (L. Venturelli), Modena-Reggio (S. Frabboni), Firenze (G. Tino), Gran Sasso, Napoli (G. De Lellis).

34

LEA PROJECTS

The 5 projects 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 is currently building 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

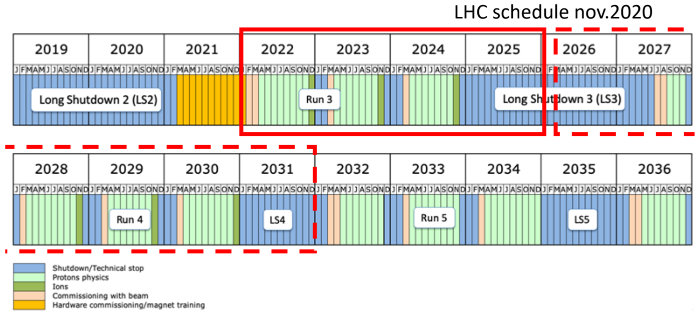
machine learning techniques can be shared between ASACUSA and ALPHA

The LEA activities, personnel and budget in the period 2022-2025

LEA activities in the period 2022-2025

Activities at AD striclty connected with CERN accelerators

LHC schedule nov.2020



Aug-Nov 2021: runs with ELENA (mainly for commissioning of the new apparatuses)

2022-2024 physics at AD-ELENA

2025 → LS3

After upgrades RUN4 (2027-2030)

Main goals in the period 2022-2025

AEgIS

- 2022: new electronic hardware for the traps; increase the pulsed production of the antihydrogen atoms in Rydberg state; first laser cooling of Ps will be attempted
- 2023: characterization of antihydrogen; studies of antihydrogen interactions with material grids
- 2024: manipulation of antihydrogen; deflectometer constructed; **first attempts for looking antihydrogen fall**
- 2025: during LS3, the apparatus will be upgraded and consolidated

ALPHA

- **first experiments on antimatter gravity** (with the ALPHA-g apparatus): first goal is to determine the sign of the gravitational force.
- improvements and upgrades to the spectroscopy apparatus (ALPHA2 --> ALPHA3) will be implemented for more stringent CPT tests.

ASACUSA

- **HFS-GS measurement** with the Rabi technique
- many improvements of the apparatus are in progress and others will be realized
- Techniques to de-excite the antiatoms in order to have antihydrogen in the ground state in the microwave cavity
- In parallel, construction of a **parasitic secondary line** for nuclear experiments

Main goals in the period 2022-2025

PsICO

- the **inertial sensing measurement** on 2^3S Ps under magnetic or laser dipole forces in the acceleration range 100 g-1000 g
- the **first proof-of-concept measurement of photons polarization** originating from the decays of metastable Ps prepared in defined magnetic quantum number states.

QUPLAS

- now: exploiting the result of QUPLAS-0 for studies of **Aharonov-Bohm effect** and **the interaction of a single quantum particle with an electromagnetic field** (a coherent quantum state).
- 2022-2023 construction of QUPLAS-I and start of data-taking
- 2024 **completion of QUPLAS-I** and finalization of the design of QUPLAS-II for studies of Ps fall.

FTE commitment 2022-2025

The LEA Collaboration

A. Alexandrov[1], T. Asada[2], G. Baù[3,4], G. Bonomi[4,5], R.S. Brusa[6,7], R. Caravita[7], F. Castelli[8,9], M. Cialdi[8,9], G. Costantini[3,4], G. Consolati[9,10], N. D'Ambrosio[2], G. De Lellis[1], R. Ferragut[9,11], M. Ferrari[3,4], V. Ferrari[3,4], S. Frabboni[12], G.C. Gazzadi[13], M. Giammarchi[9], G. Gosta[3], V. Grillo[13], M. Leali[3,4], G. Maero[8,9], S. Mariazzi[6,7], V. Mascagna[4,14], S. Migliorati[3,4], E. Pasino[8,9], L. Penasa[6,7], L. Povolo[6,7], F. Prelz[9], G. Pozzi[15,16], M. Romé[8,9], G. Rosi[17], L. Salvi[17,18], S. Sharma[7], L. Solazzi[4,5], F. Sorrentino[19] S. Stracka[20], G. Tino[17,18], V. Tioukov[1], V. Toso[9,11], M. Urioni[4,5], L. Venturelli[3,4], G. Vinelli[17,18], M. Volponi[6,7,21], N. Zurlo[4,22]

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

N.B. The increase ot the partecipants will not significantly increase the Common Fund costs (mainly due to engagement in technological activities)

Budget envelope 2022-2025

	2022	2023	2024	2025
AEgIS	125	145	115	95
ALPHA	15	20	35	45
ASACUSA	65	35	35	30
PsICO	55	65	55	15
QUPLAS	50	50	40	30
Total	310	315	280	215

k€

- Common fund costs included (but no common funds for PsICO and QUPLAS)
- Travel costs excluded

Budget envelope 2022-2025

AEgIS

30 k€ of common fund (about 10 researchers)
30 k€ for consumables and maintenance of the apparatuses
in 2022, co-funding of a new 50 mCi radioactive Na22 source (about 40 k€)
in 2023-24 (80+20 k€) for the construction of the moire deflectometer
About 10-15 k€ / year are related to the set-up: the goal is to become independent from the CERN POOL (cost of renting)
About 9 person-months per year are required for travel expenses to CERN for data taking and hardware implementation.

ALPHA

For the first years mainly for common funds (about 14 k€).
Then implementation of a new system of external detectors
Software activities of the experiment, mainly in the field of simulations (Geant4 Virtual Monte Carlo), analysis data and development of machine learning algorithm for track reconstruction and events selection
Permanent onsite presence, for each participating Institute, of a PhD or young post-doc

ASACUSA

In 2022 contribution to the construction of the differential pumping system for the secondary beam line (25-30 k€) and contribution to the purchase of a new positron source.
In 2025 a contribution will be also possible for the construction of the detector for Pontecorvo measurements.
For data-taking 1{1.5 researchers at CERN during 2022-2024
In all years the common fund expenses are about 15 k€ per year (8 researchers)

PsICO

In 2022 the main cost (45 k€) will be for the construction of the new pulsed positron beam
The laser system will be assembled with external founds (about 40 k€) from Fellini grant and 20 k€ for the purchase of detectors and a fast oscilloscope from UniTrento Starting Grant
In 2023, 20 k€ for the completion of the positron beam; 45 k€ for the construction of the positron re-bunching system
In 2024, 45 k€ for apparatus
In 2025, the main expenditure will be contribution for consumables (15 k€)
Two person-months per year are required for travel expenses for measurements with the positron system at CERN.
No common funds are needed

QUPLAS

For the QUPLAS-I phase the financial request will be of 140 k€, distributed in 2022, 2023 and 2024 for new beamline for Ps generation, laser systems and optical cavities
After 2024, QUPLAS-II needs 260 k€, mainly fo laser systems to excite Ps Rydberg states.
External funding: 10 k€ form UniMI for QUPLAS-0, PoliMI 50 k€ for Na-22 source and 15 k€ per year for the lab.
Application for funding from UniMI and PRIN for QUPLAS-0.
No common funds are needed

CONCLUSIONS

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