QUPLAS

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On behalf of the QUPLAS group (Collaboration)

Q U P L A S

QUantum Interferometry, decoherence and gravitational studies with Positrons and LASers

Outline of talk:

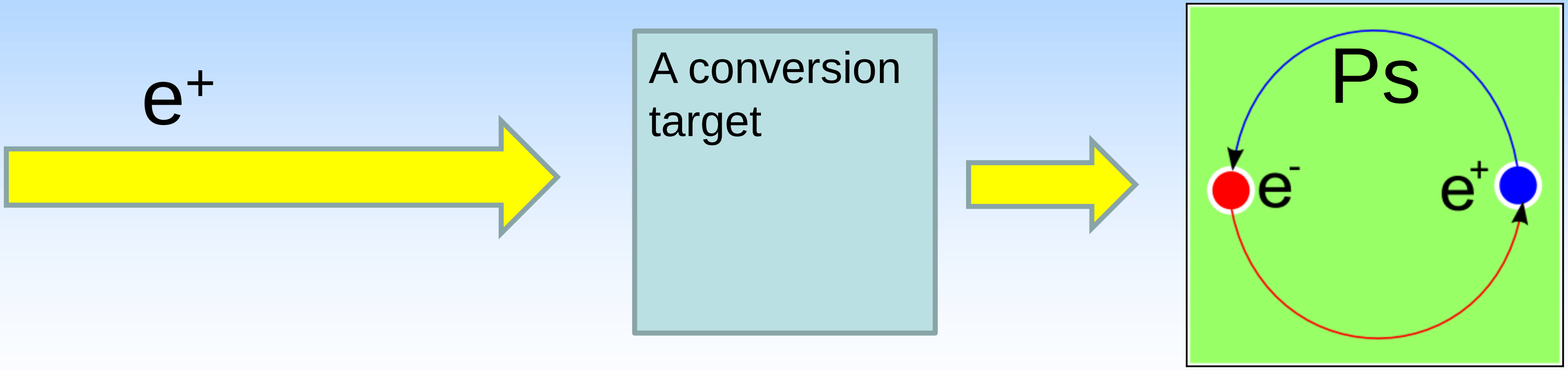
- **QUPLAS Concept**
- **QUPLAS Physics**
- **QUPLAS Proposal and Financial Issues**

Home of the Experiment:

L-NESS Laboratory of the

Milano Politecnico in Como

Positrons and Positronium (Ps)



ortho-Ps is short lived

But its lifetime can be increased by exciting it on a Rydberg (high-n) state

$$\tau \approx n^3 \, l^2$$

The metastable electron-positron bound state can exist in different configurations depending on the relative spin states of the positron and the electron. These are known as para-positronium (p-Ps), with total spin S = 0 and ortho positronium (o-Ps) with S = 1.

These spin states have very different lifetimes:

$$|S,m\rangle = |0,0\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle\right)$$

$$|S,m\rangle = |1,0\rangle = \frac{1}{\sqrt{2}}\left(|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle\right)$$

$$|S,m\rangle = |1,1\rangle = |\uparrow\uparrow\rangle$$

$$|S,m\rangle = |1,-1\rangle = |\downarrow\downarrow\rangle$$

$$\tau_{\text{p-Ps}} = 125 \text{ ps}$$

$$\tau_{\text{o-Ps}} = 142 \text{ ns}$$

Any process that converts o-Ps to p-Ps is easy to see in lifetime spectra

The QUPLAS Collaboration

Università degli Studi di Milano and Infn Milano
S. Castelli, S. Cialdi, M. Giammarchi*, M. Longhi, G. Maero, Z. Mazzotta,
S. Olivares, M. Paris, M. Potenza, M. Romè, S. Sala, S. Siccardi, D. Trezzi

Politecnico Como (Milano)
S. Aghion, M. Bollani (IFN del CNR), G. Consolati, C. Evans, M. Leone, R. Ferragut

Albert Einstein Center – Laboratory for HEP – University of Bern
A. Ariga, T. Ariga, A. Ereditato, C. Pistillo, P. Scampoli

Dep.t of Chemistry, University of Bath
K. Edler

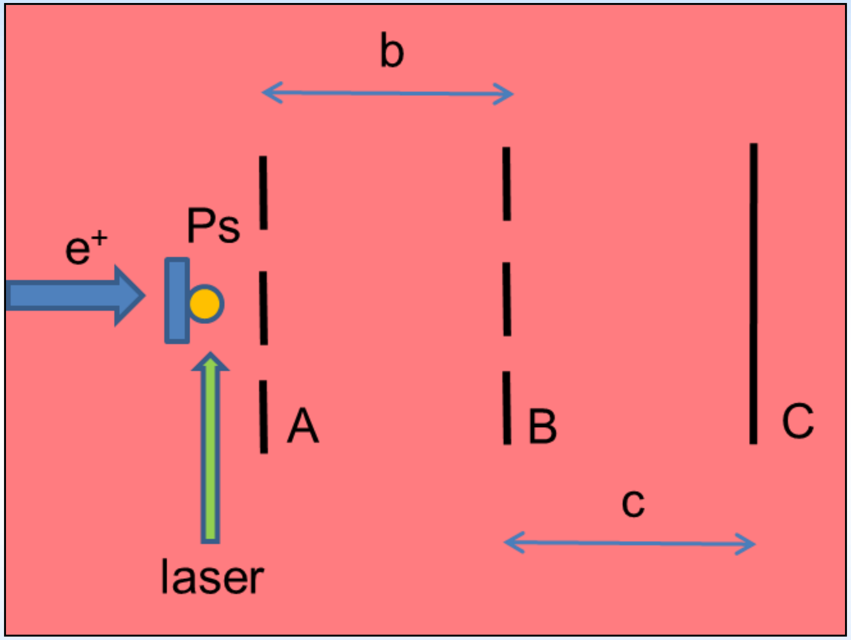
R. Greaves (Los Angeles, formerly at First Point Scientific)

Introduction to the concept of Quantum Interferometry of Ps

The typical structure of a Quantum Mechanical Experiment

Preparation :

- e+ beam
- Ps beam
- Target
- Laser (excitation)
- First grating



Detection :

- Recording interference pattern
- Projection on measurement eigenstates

Preparation

Interaction
Propagation
Interference

Detection

Non – ideality :
Incoherence

Non – ideality :
Decoherence

QUPLAS concept

Synergy of technologies developed in different areas as well as new technologies:

- Positrons and positronium techniques (Como)
- Positron beams, moderation and plasmas (Como, Milano)
- Special converters for Ps production in transmission mode (Bath, Milano)
- Laser excitation for positronium (Milano)
- Emulsion techniques for precise measurements (Bern)

↓

New Fundamental Physics

QUPLAS Physics

Quantum Interferometry (mostly) in the Talbot regime

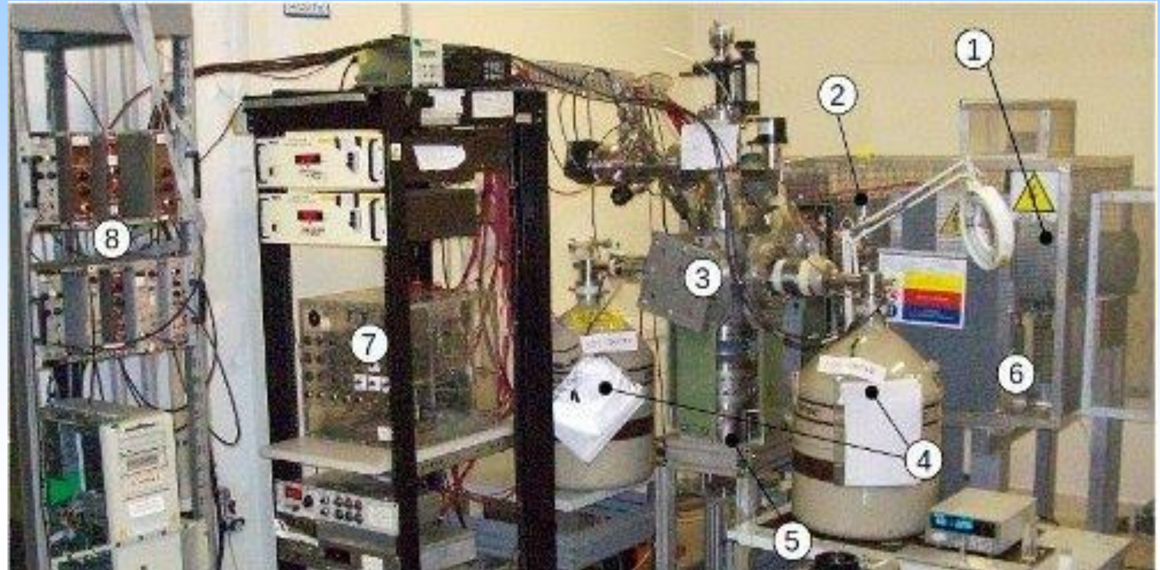
S. Sala, F. Castelli, M. Giammarchi, S. Siccardi and S. Olivares – Matter-wave interferometry: towards antimatter interferometers. Submitted to J. of Phys. B, Atomic, Molecular and Optical Physics, arxiv:1505.01639 [quant-ph].

- Positrons and electrons quantum waves interference (QUPLAS-0)
- Positronium quantum interference (QUPLAS-I)
- Positronium quantum mechanics and decoherence studies
- Positronium gravitational studies : free fall ! (QUPLAS-II)

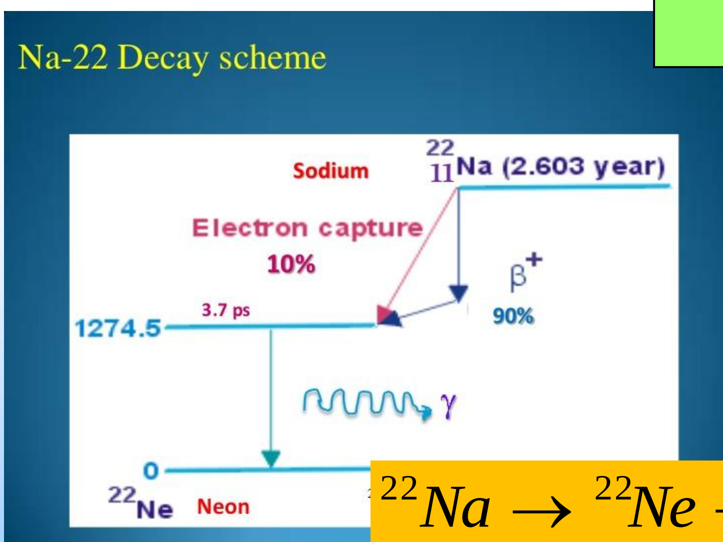
The facility: the Como continuous positron beam

The VPAS Laboratory at the L-Ness Politecnico di Milano at Como Center. (R. Ferragut)

Slow positron beam. 1. Radioactive source; 2. Electrostatic optics; 3. Sample chamber; 4. HpGe detectors; 5. Cryostat; 6. High voltage protection cage; 7. Power suppliers; 8. Detector electronics.



http://www.como.polimi.it/positron



Original intensity of the source: 50 mCi
Current intensity: ~ 13 mCi

Tungsten moderator → reduces the energy from the beta spectrum down to a few eV
Electrostatic transport → positron beam

$$^{22}Na \rightarrow {}^{22}Ne + e^{+} + \nu_e + \gamma$$

Positron beam energy: from a few keV up to 20 keV

Reference value: 10 keV

Intensity: ~ 4 x 10^4 e^+/s

$$T = 10 \quad keV \qquad v = 6 \times 10^7 \quad m/s$$

The de Broglie wavelength

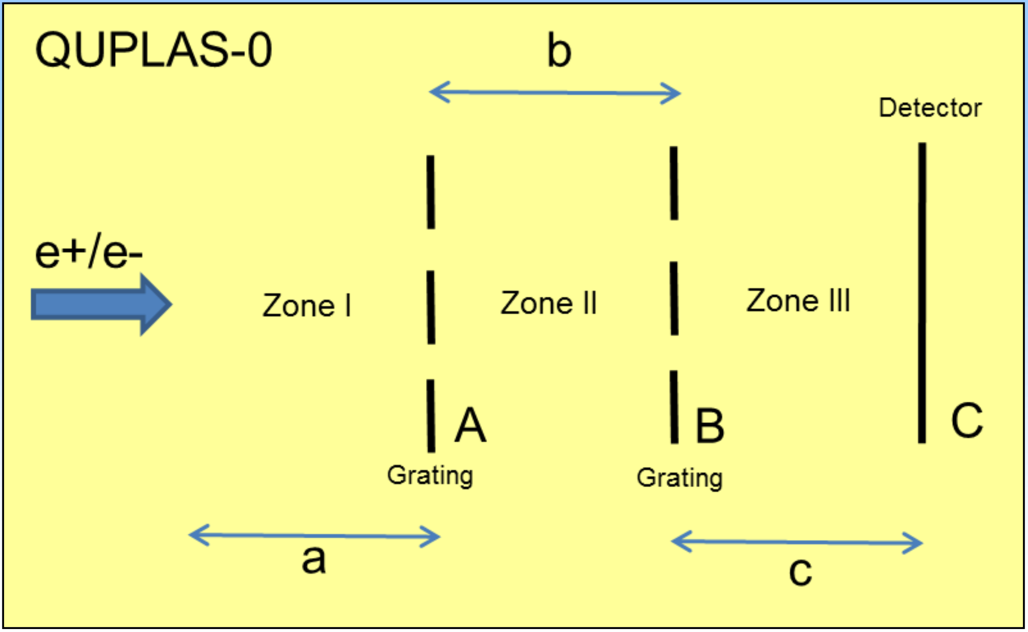
$$\lambda = \frac{h}{mv} = 1.2 \times 10^{-11} \quad m$$

Given a grating with

$$d = 2 \quad \mu m$$

The Talbot length

$$L_T = \frac{d^2}{\lambda} = 33 \quad cm$$



One can choose b = c = 33 cm

To have a 2 µm periodicity pattern on C

- Setup preparation
- Exposure to the e^+ beam
- Integration on the emulsion detector C

QUPLAS - I

Positronium Quantum Interferometry concept

Why?

- Positron Interferometry
- Electron Interferometry

- Positronium Interferometry

An elementary fermion
The relevant antifermion

The bound fermion-antifermion system
(also, the simplest atom)

Problems to face :

- Positronium is a neutral atom

Detection of the interference pattern is not going to be easy. Ionization required.

- Positronium has a very short lifetime

Excitation on Rydberg state is necessary. Laser excitation required.

QUPLAS - II

Positronium Gravity : why?

Answer : to test the Weak Equivalence Principle (test of General Relativity)

Universality of Free Fall

Matter

- Weak Equivalence Principle tested on many different systems
- Torsion Balance Measurement
- 10^{-13} level reached

Antimatter

- g not measured
- Antihydrogen program at CERN (e. g. The AEgIS experiment)
- Aiming at 1% accuracy

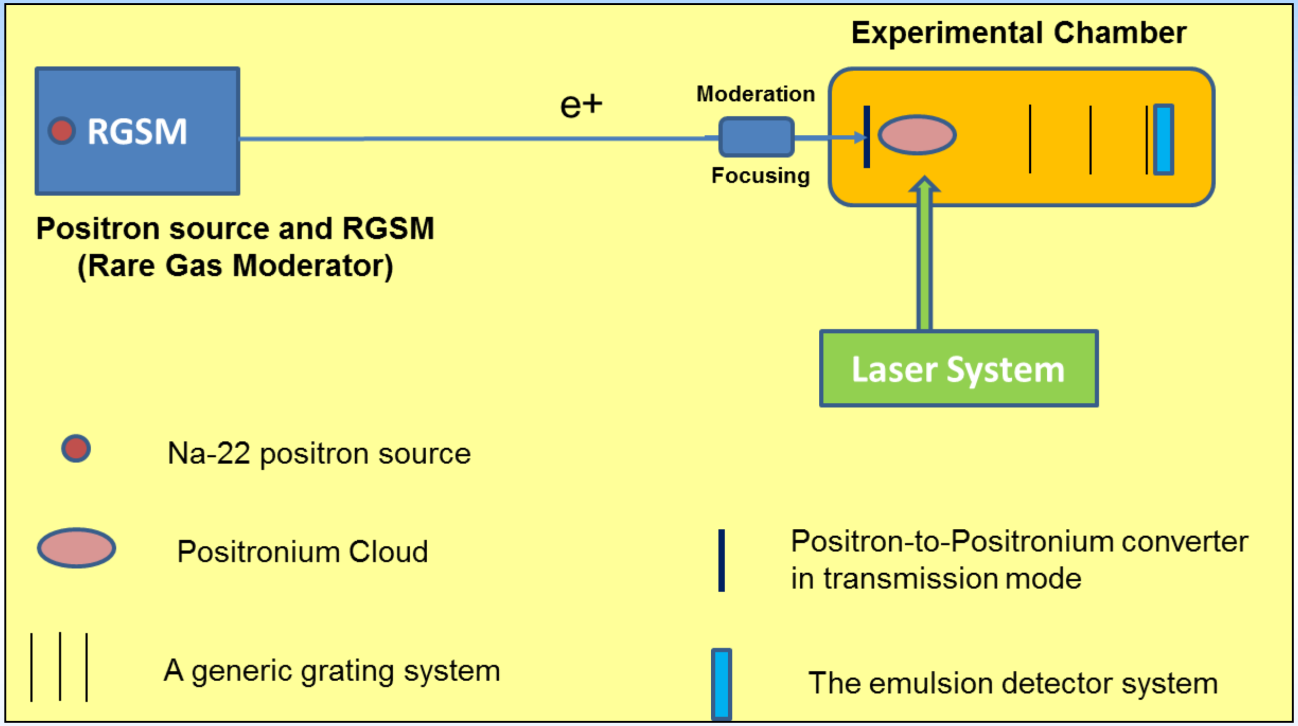
Positronium

- Matter/Antimatter system

?

QUPLAS Proposal and Financial Issues

General structure :



- Positrons and electrons quantum waves interference (QUPLAS-0)
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QUPLAS Proposal and Financial issues

QUPLAS – 0 activity already taking place

- QUPLAS-0 activity is already supported by :

- Politecnico di Milano (use of the VEPAS Laboratory)
- University of Bern (operation, development, use of the emulsion detectors)
- University of Bath (transmission targets development)

The full capital cost of the experiment is roughly of about :
150 kEur (moderator)
250 kEur (laser system)
200 kEur (gratings,beamline,detectors)

- Request for an ERC Advanced Grant presented (PI: M. Giammarchi)

- Possible FET for the laser part (S. Cialdi)

The Infn proposal
(in preparation, preliminary)

Infn Milano :

Stefano Aghion (AsRic Politecnico)	50%
Monica Bollani (IFN Cnr Politecnico)	20%
Fabrizio Castelli (RU Dipartimento)	50%
Simone Cialdi (RU Dipartimento)	50%
Giovanni Consolati (PA Politecnico)	50%
Rafael Ferragut (PA Politecnico)	50%
Marco Giammarchi (PR Infn)	50%
Mariangela Longhi (RU Dip. Chimica)	20%
Giancarlo Maero (RUTD Dipartimento)	15%
Stefano Olivares (RU Dipartimento)	50%
Matteo Paris (PA Dipartimento)	50%
Marco Potenza (RU Dipartimento)	40%
Massimiliano Romè (RU Diparitmento)	15%
Davide Trezzi (AsRic UNIMI)	20%
TOTAL	530%

- We will require Infn approval and will discuss a flexible financial profile
- 2016 request will focus on the support of QUPLAS-0 (and possibly some laser development)
- (Major investments will be proposed only after QUPLAS-0 will demonstrate the technology)

2016 (yet preliminary)

Costruzione Apparati	18 k Eur (interferometers, laser optics)
Consumi	10 k Eur (gratings, targets)
Trasferte	10 k Eur