



POLITECNICO
MILANO 1863



Antimateria

Aplicaciones y estudios fundamentales

Rafael Ferragut



RCAI

Red de Científicos Argentinos en Italia

**Primera Conferencia Científica
Bologna, 3 de diciembre 2016**



Yolanda y Rafael



Silvina, Pedro e Irene



Bs.As.

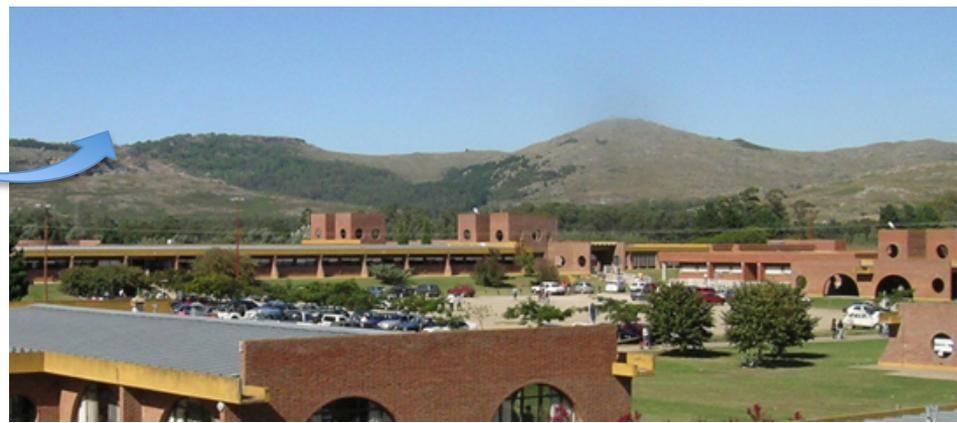


Bs.As.

Tandil



Alberto Somoza



UNICEN

Universidad Nacional del Centro
de la Provincia de Buenos Aires



Como



Brunate



POLITECNICO
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Alfredo Dupasquier

➤ Presentación: VEPAS lab



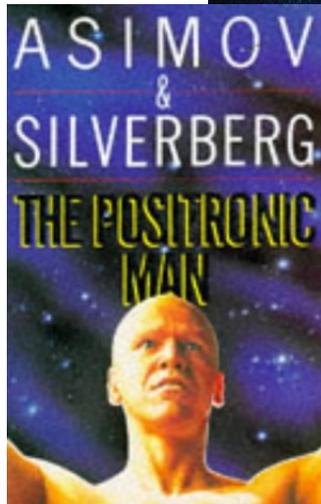
**VEPAS lab - Variable Energy Positron Annihilation Spectroscopy
Politecnico di Milano – Como campus**



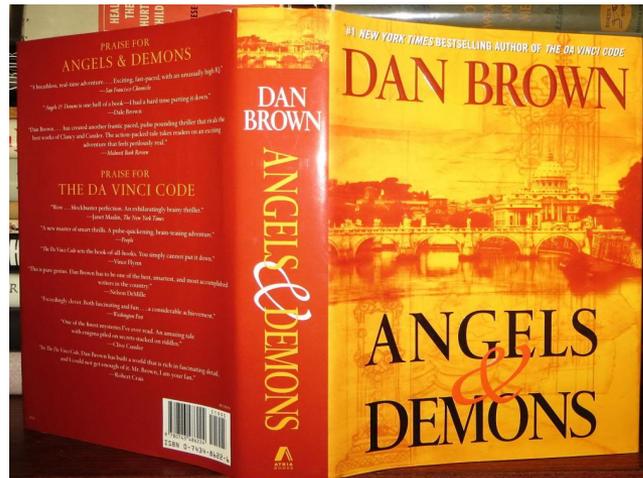
Grupo: *Stefano Agnion (Bologna, Italy); Craig Evans (Swansea, Wales, UK); Erasmo Dei Cas (Valtellina, Italy); Rafael Ferragut (Buenos Aires, Argentina)*



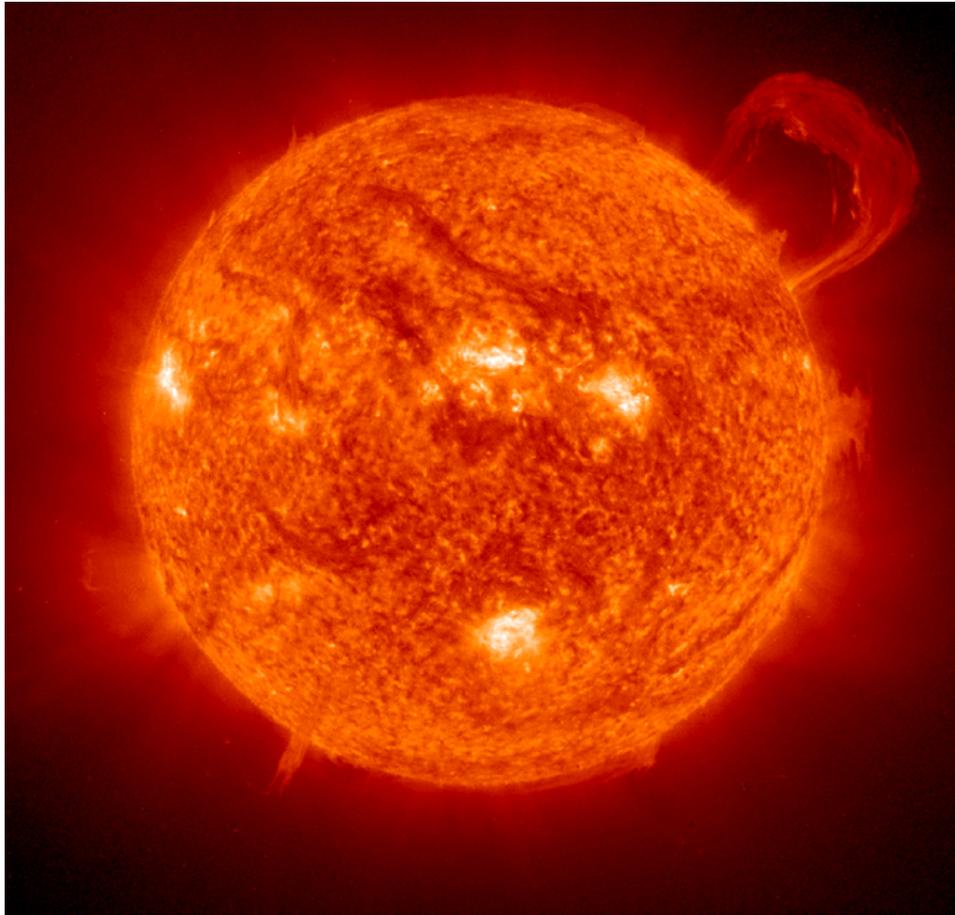
➤ ¿Qué es la antimateria? ¿Sólo ciencia ficción?



(The Positronic Man)

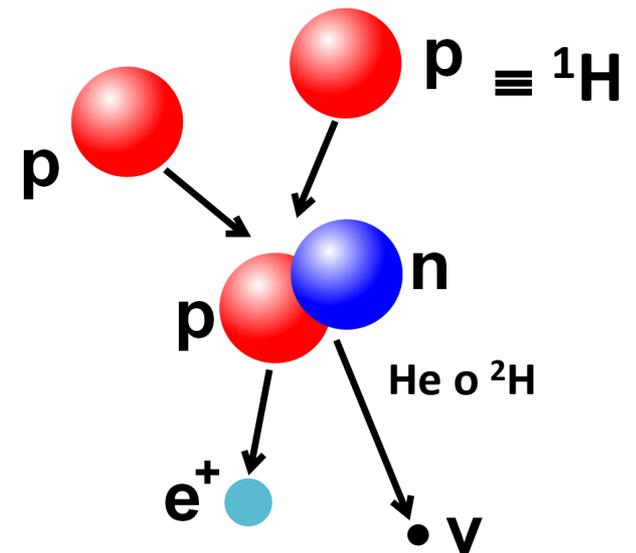


¿Usamos la antimateria cotidianamente?



El sol

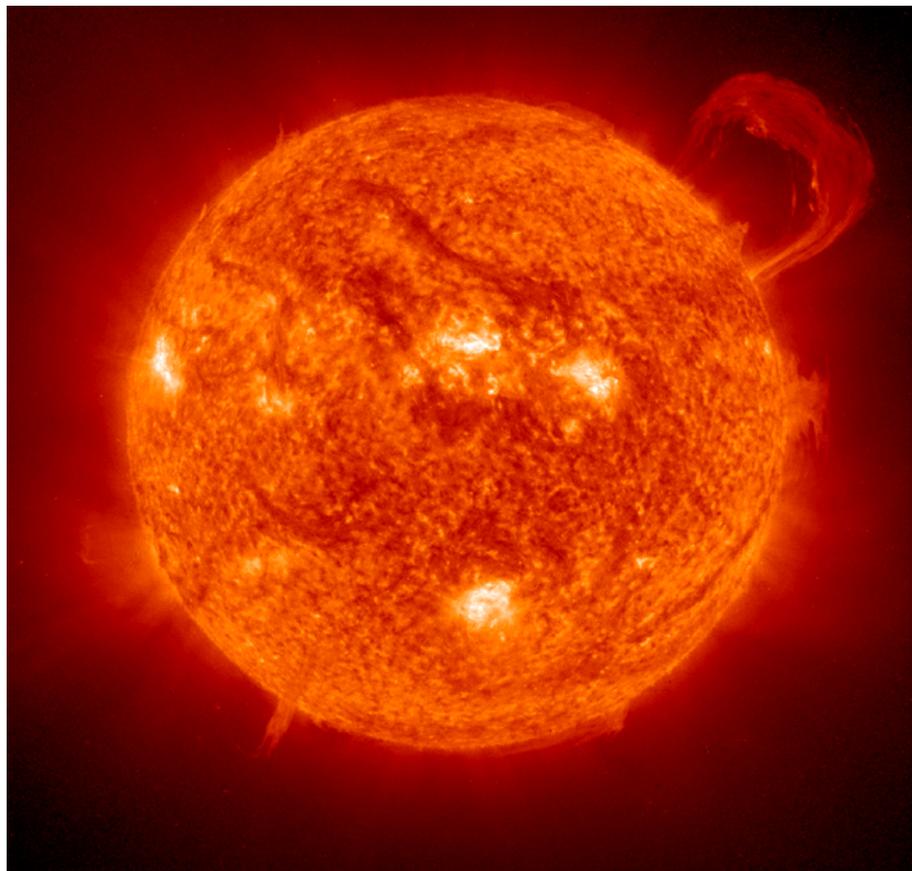
Núcleo
15-16 millones de grados
500 mil millones de atmósferas



Aniquilación electrón-positrón e^-e^+

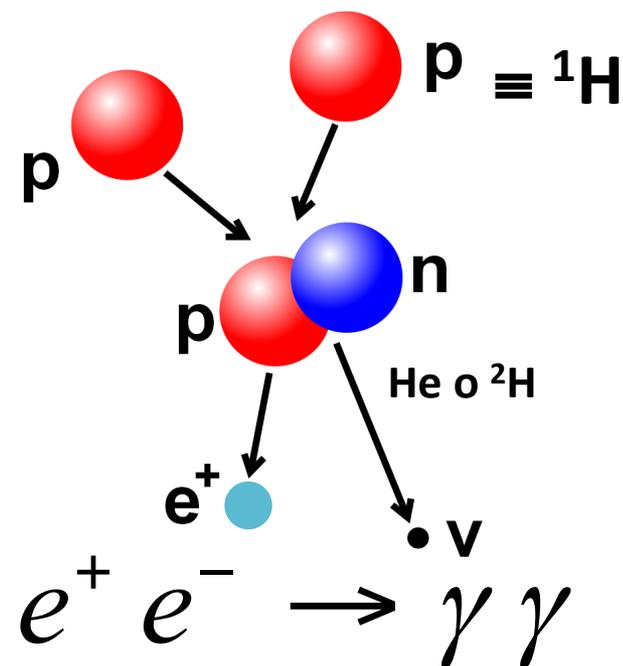


¿Usamos la antimateria cotidianamente?



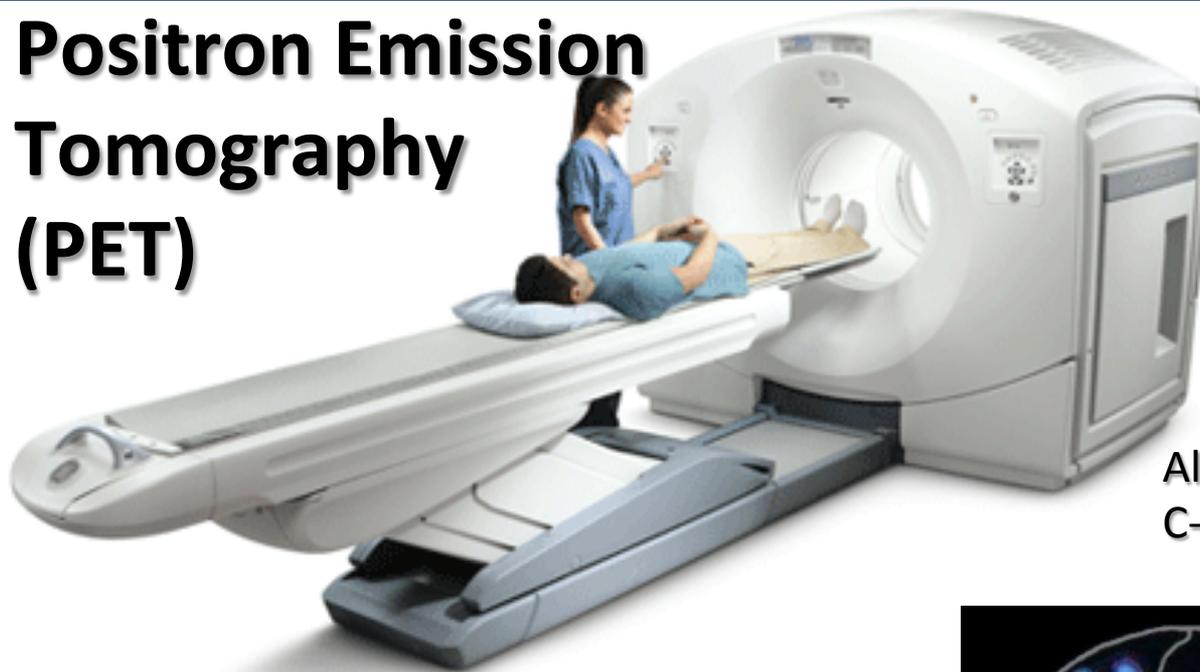
El sol

Núcleo
15-16 millones de grados
500 mil millones de atmósferas

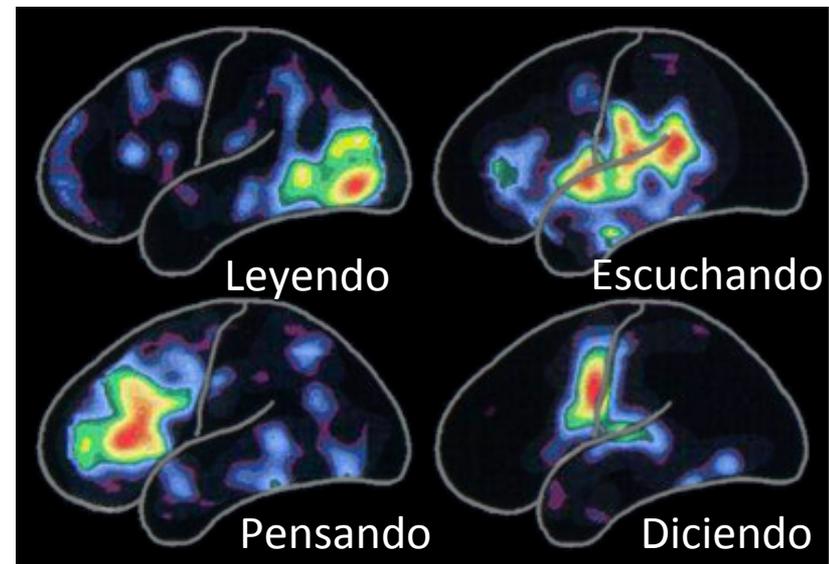
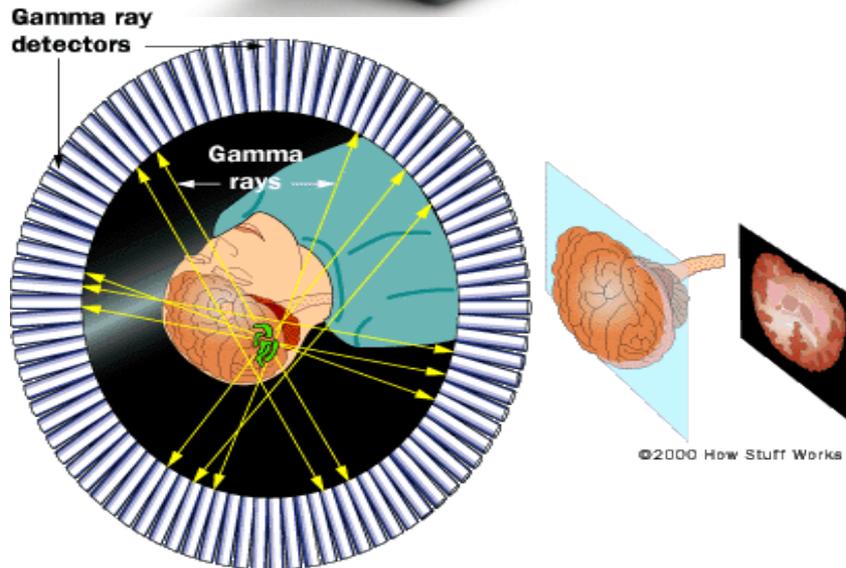


100.000 años!!!

Positron Emission Tomography (PET)

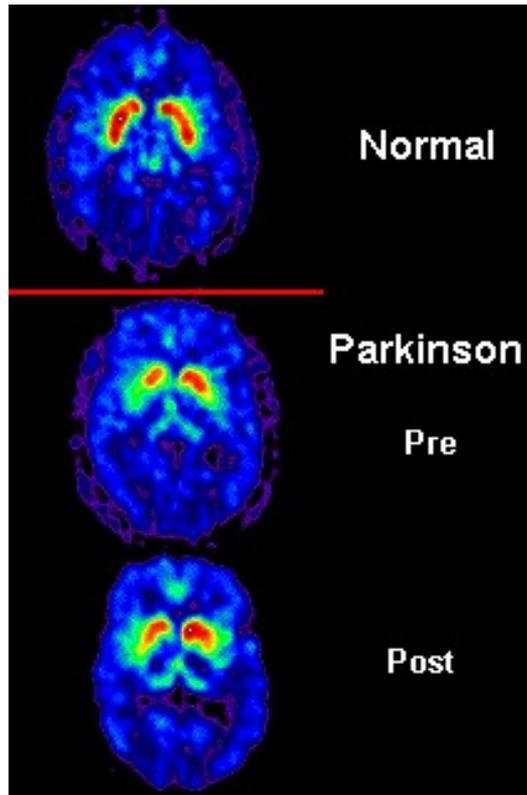


Algunos elementos trazadores:
C-11, Fl-18, O-15 or N-13

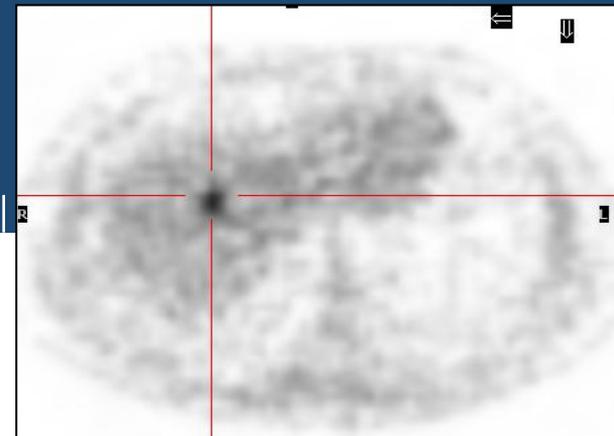


Algunas actividades cerebrales

Diagnostico precoz de enfermedades degenerativas y tumores



PET



TC



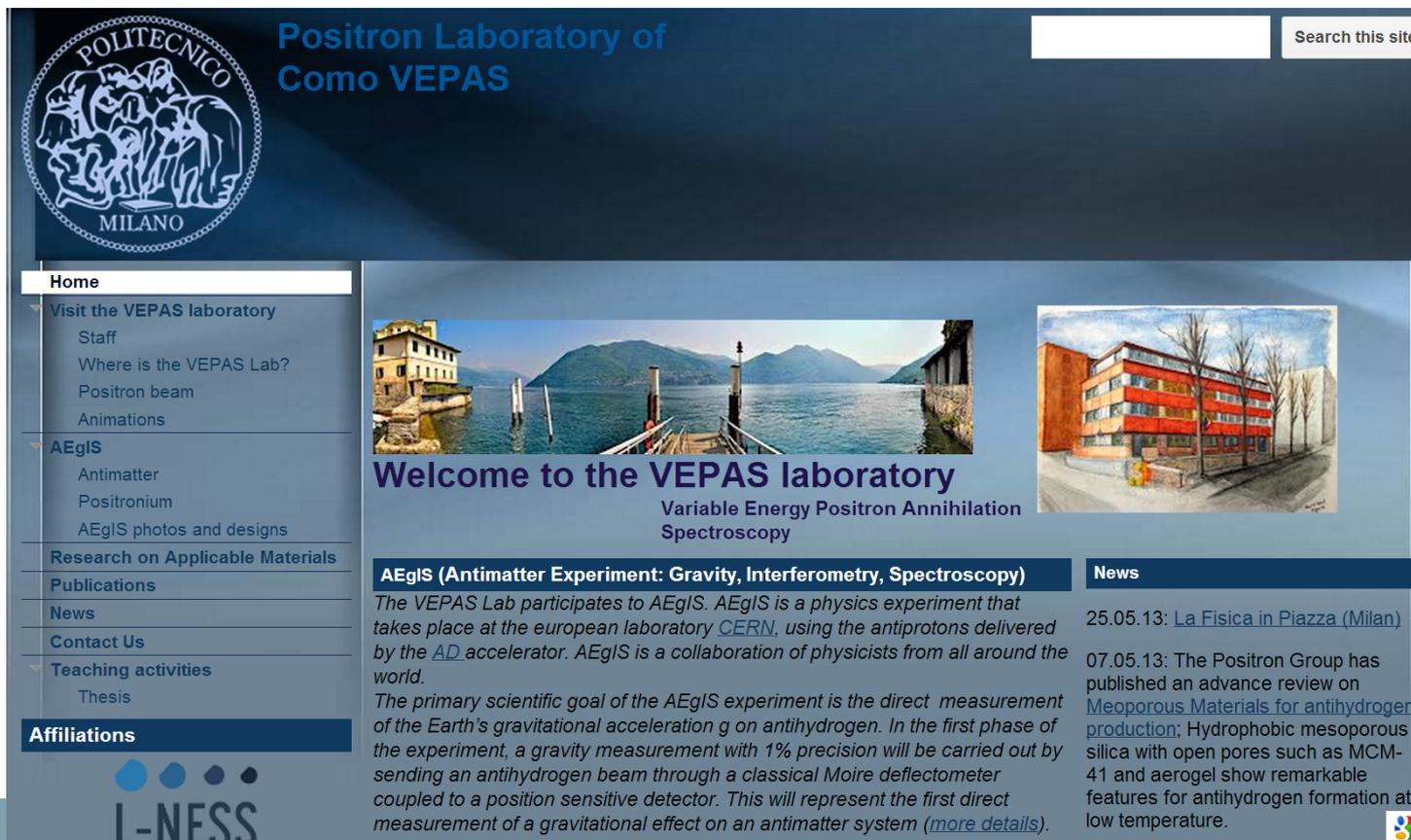
PET + TC



La antimateria también se usa para estudiar la materia

Positron Laboratory Politecnico di Milano -Dipartimento di Fisica Polo Territoriale di Como

Stefano Agnion, Craig Evans,
Erasmus Dei Cas e Rafael Ferragut



Positron Laboratory of Como VEPAS

Search this site

Home

- Visit the VEPAS laboratory
 - Staff
 - Where is the VEPAS Lab?
 - Positron beam
 - Animations
- AEgIS
 - Antimatter
 - Positronium
 - AEgIS photos and designs
- Research on Applicable Materials
- Publications
- News
- Contact Us
- Teaching activities
 - Thesis

Affiliations

Welcome to the VEPAS laboratory
Variable Energy Positron Annihilation Spectroscopy

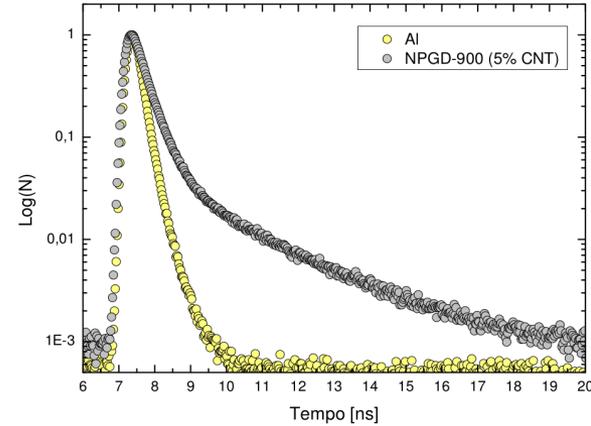
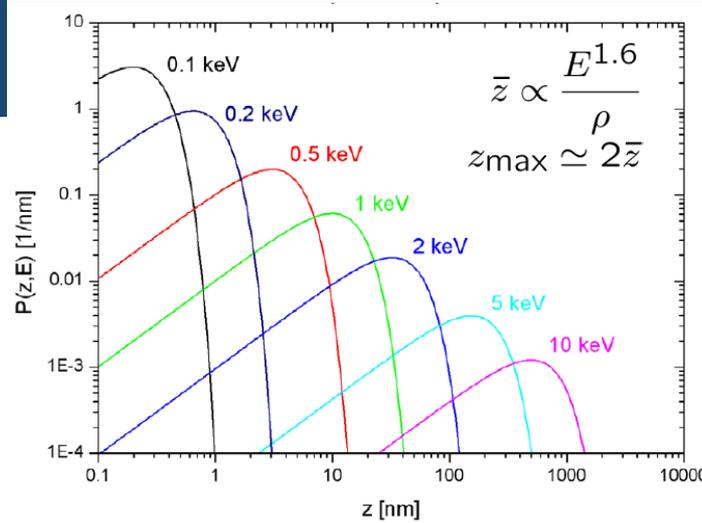
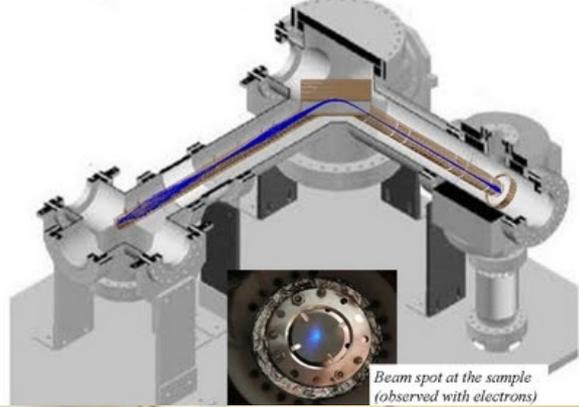
AEgIS (Antimatter Experiment: Gravity, Interferometry, Spectroscopy)
The VEPAS Lab participates to AEgIS. AEgIS is a physics experiment that takes place at the european laboratory CERN, using the antiprotons delivered by the AD accelerator. AEgIS is a collaboration of physicists from all around the world.
The primary scientific goal of the AEgIS experiment is the direct measurement of the Earth's gravitational acceleration g on antihydrogen. In the first phase of the experiment, a gravity measurement with 1% precision will be carried out by sending an antihydrogen beam through a classical Moire deflectometer coupled to a position sensitive detector. This will represent the first direct measurement of a gravitational effect on an antimatter system ([more details](#)).

News

25.05.13: [La Fisica in Piazza \(Milan\)](#)

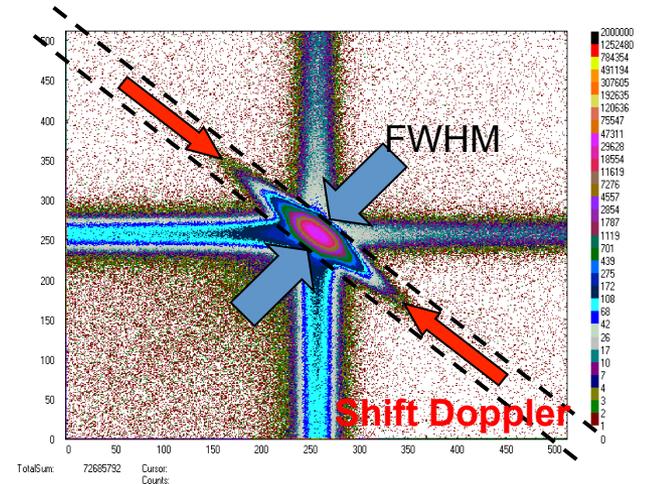
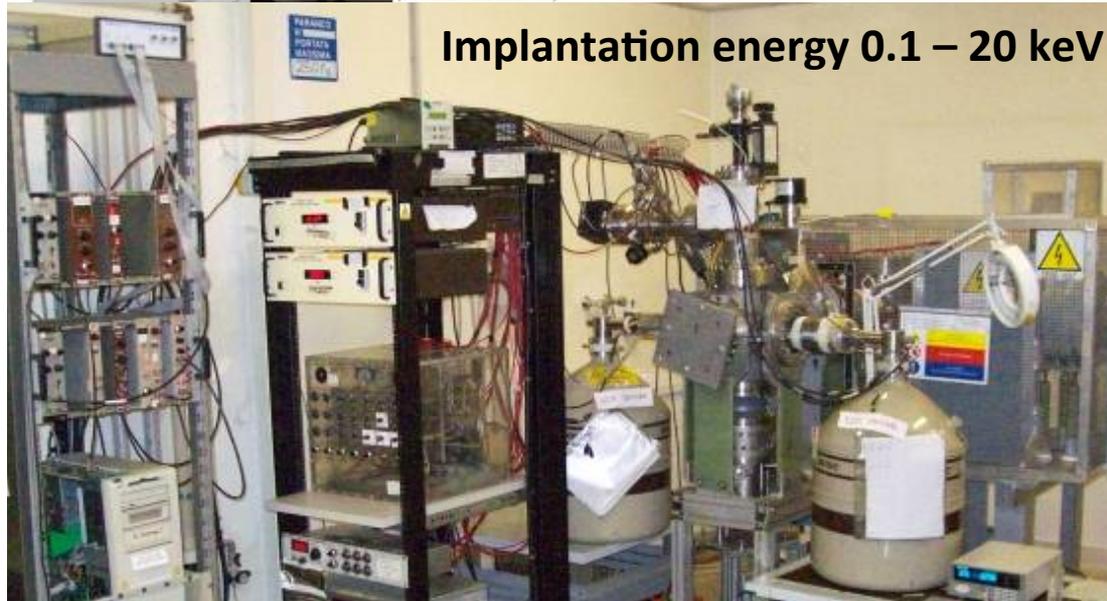
07.05.13: The Positron Group has published an advance review on [Meoporous Materials for antihydrogen production](#); Hydrophobic mesoporous silica with open pores such as MCM-41 and aerogel show remarkable features for antihydrogen formation at low temperature.

Haz de antimateria



Positron Lifetime Spectroscopy

Implantation energy 0.1 – 20 keV



coincidence Doppler broadening

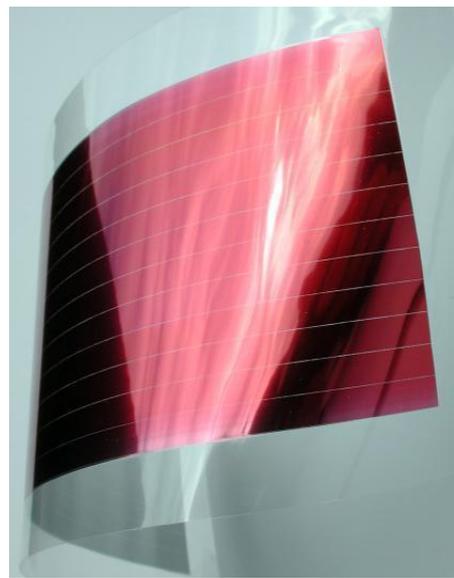
Se estudian materiales avanzados: semiconductores, aleaciones metalicas, oxidos y polimeros; para campos que van desde la producción de energia renovable (celdas solares) a materiales usados en obras artísticas.



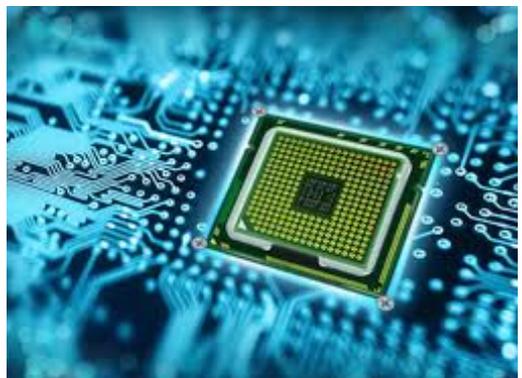
Aleaciones livianas



Polimeros: arte contemporáneo



Celdas solares
Energy & Environ. Sci. **5**
9068 (2012) (I.F.: **25.427**)



Semiconductores

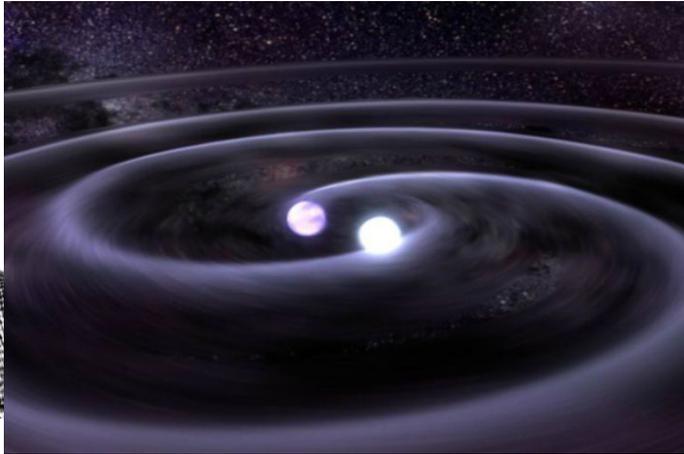


**Oxidos metálicos,
perovskitas, etc.**

...y otras aplicaciones...

➤ ¿Cómo nace la antimateria?

TEORIA DE LA RELATIVIDAD



MECANICA CUANTICA

$$\det |(E_i^{(n)} - E) \delta_{ij} + V_{ij}^{(n)}| = 0; \quad i, j = 1, 2$$
$$V_{ij}^{(n)} = \int U_i^{(n)*} \hat{V} U_j^{(n)} d\tau_A; \quad \Psi_n^{(n)} = \left\{ \alpha_1^{(n)}, \alpha_2^{(n)}, \dots, \alpha_n^{(n)} \right\}$$
$$\sum |\alpha_i|^2 = 1$$
$$V_{12} \frac{1}{E^{(-)} - H_2} V_{12}^+ \rightarrow V_{12} \Phi_2^{(n)} \rangle \cdot \frac{1}{E^{(-)} - H_2}$$
$$\langle \Phi_2^{(n)} | V_{12}^+ \int dE' \frac{2\pi (E' - E_2)^{-1} + \frac{1}{\gamma} \Gamma_2}{E^{(-)} - E'} \Phi_2^{(n)} \rangle$$
$$V_{12} \frac{1}{E^{(-)} - H_2} V_{12}^+ = \frac{1}{E - (E_2 + i \frac{\Gamma_2}{2})}$$
$$M_{0 \rightarrow 1} = \langle \Psi_{U_1} | \hat{H}_1 | \Psi \rangle + \frac{\langle \Phi_2^{(n)} | V_{12}^+ U_1 \rangle}{E - (E_2 + i \frac{\Gamma_2}{2})} \langle \Psi | \Phi_2^{(n)} / H_1 \rangle$$



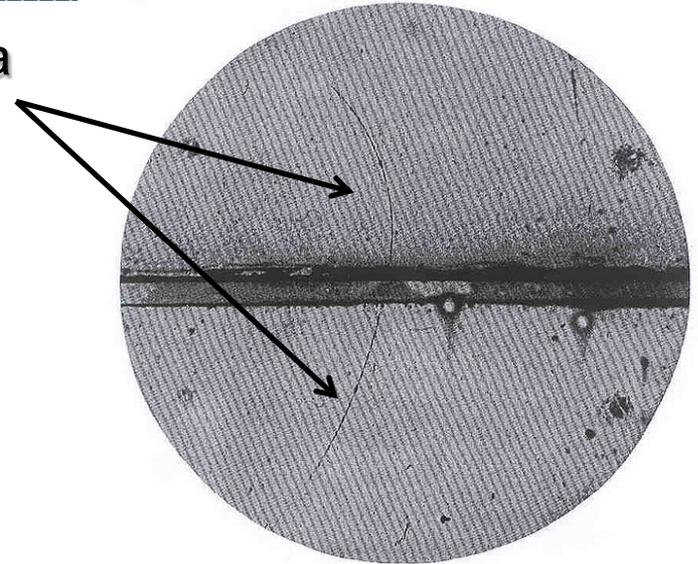
1928: La hipótesis de Paul Dirac

Primera partícula de antimateria descubierta: el positrón

El positrón fue descubierto en una cámara de niebla por su interacción con los rayos cósmicos (Anderson, 1932).



Carl David Anderson

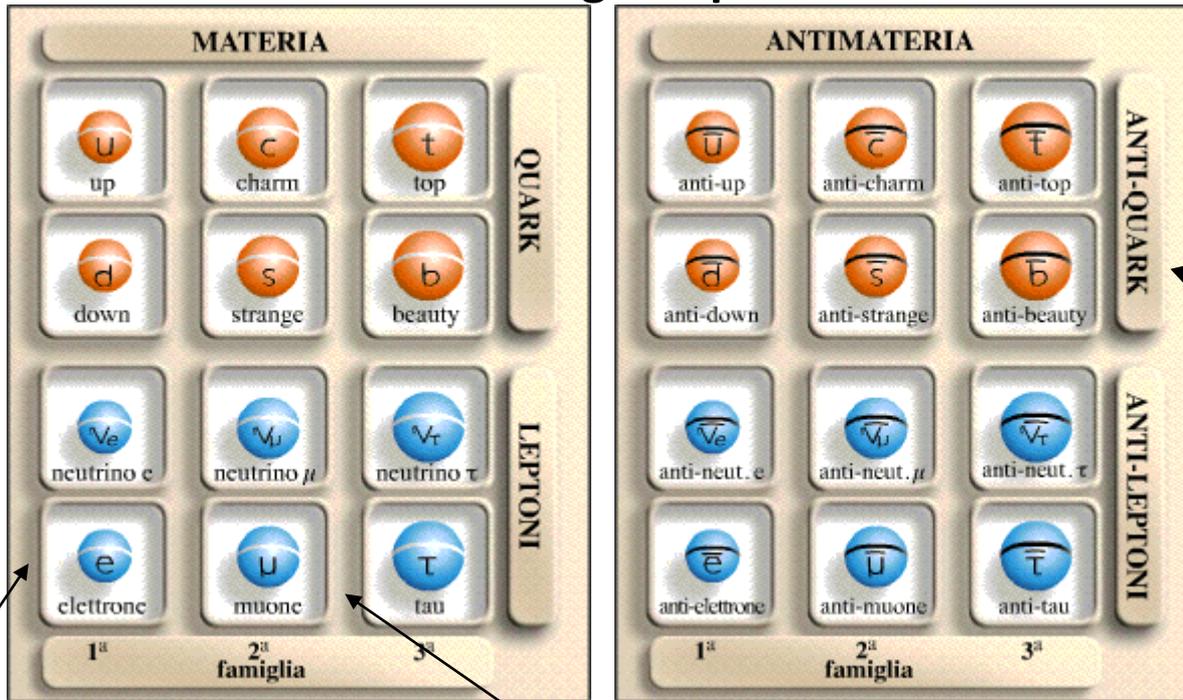


Antipartícula: la misma masa de la partícula y carga opuesta

Materia/antimateria

Costituenti fondamentali della materia: Quark e Leptoni

La antimateria è l'immagine speculare della materia



I costituenti fondamentali hanno tutti un'antiparticella !

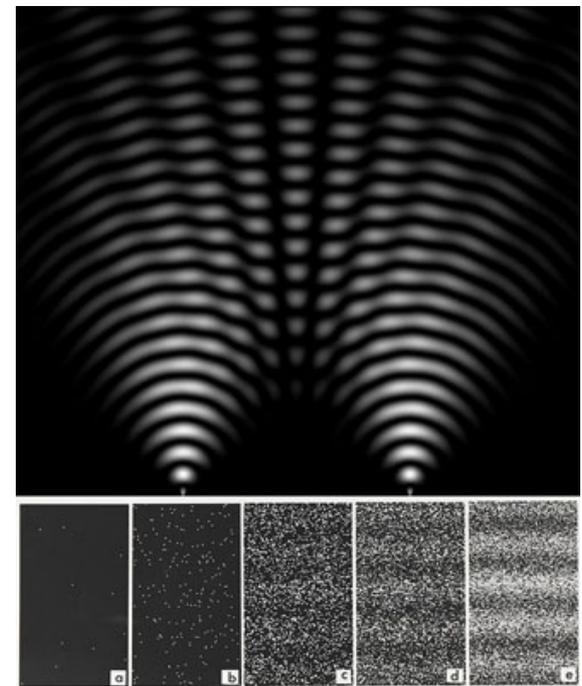
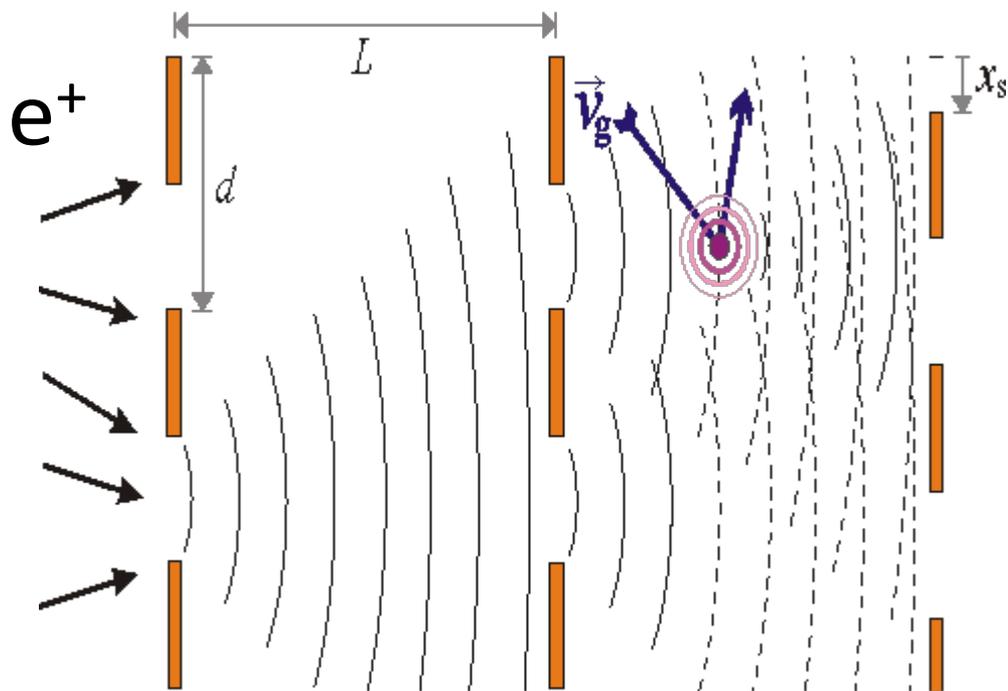
Costituiscono la materia in condizioni ordinarie

Costituiscono le particelle instabili

Decadono in particelle stabili

QUPLAS

QUantum Interferometry, decoherence and gravitational studies with Positrons and LASers



QUPLAS-0: Positron interferometry

- Positron beam energy: from a few keV up to 20 keV
- Reference value: 10 keV
- Intensity: $\sim 1 \times 10^4 \text{ e}^+/\text{s}$

$$T = 10 \text{ keV} \quad v = 6 \times 10^7 \text{ m/s}$$

The de Broglie wavelength

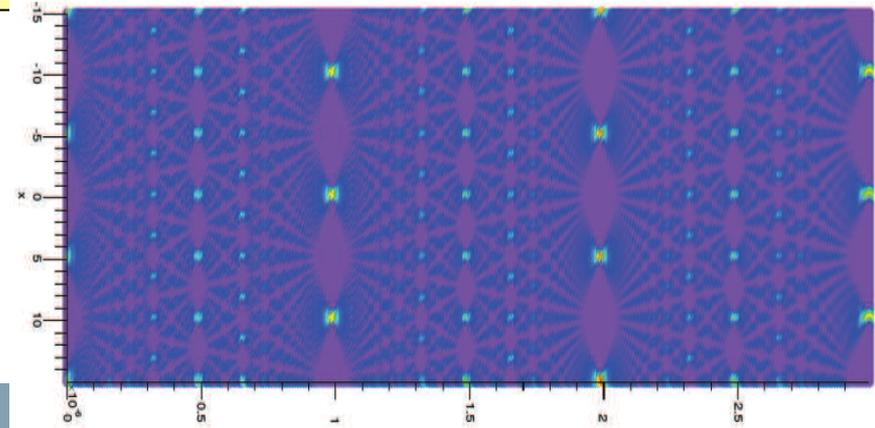
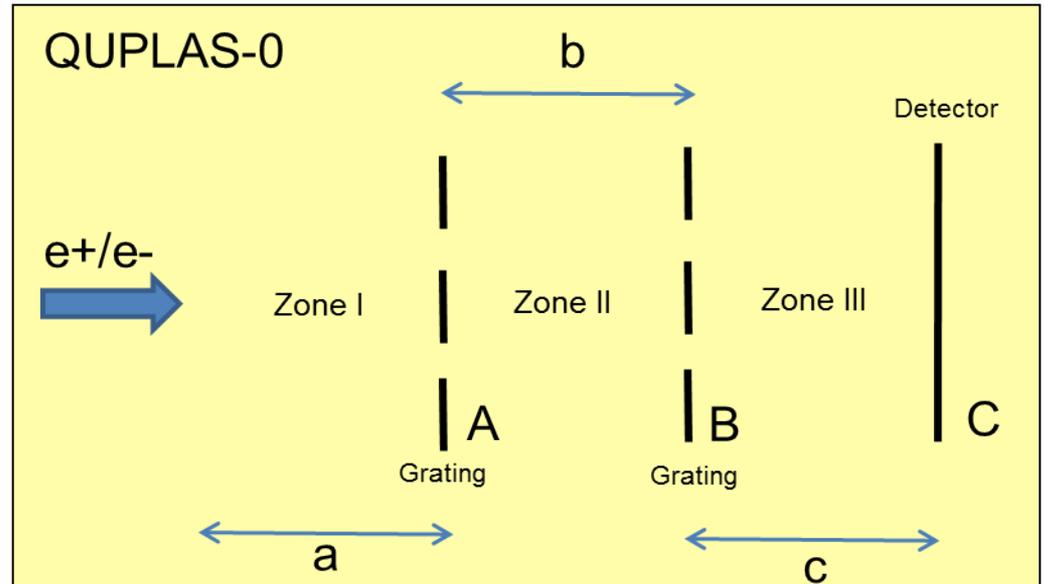
$$\lambda = \frac{h}{mv} = 1.2 \times 10^{-11} \text{ m}$$

Given a grating with

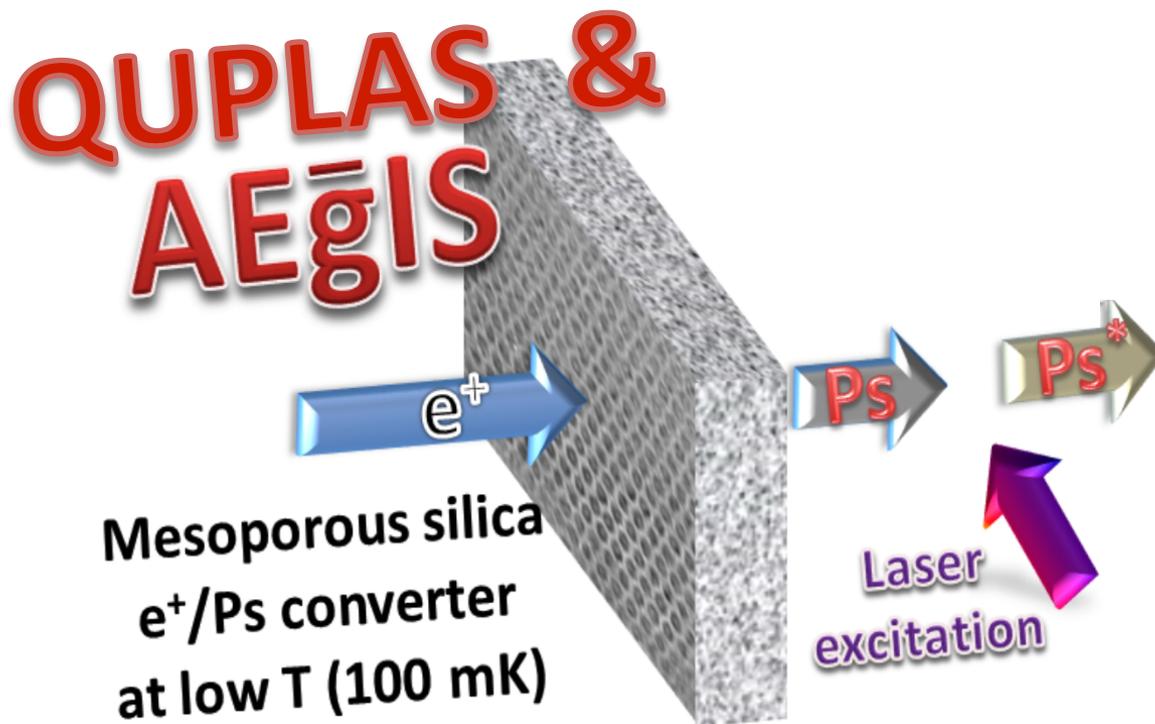
$$d = 2 \text{ } \mu\text{m}$$

The Talbot length

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



QUPLAS-I: Positronium interferometry



Chemical Society Reviews **42**, 3821 (2013) (I.F.: **34.09**)

QUPLAS-I: Interferometria con Positronio

QUPLAS development phases:

- Positrons and electrons quantum interference (QUPLAS-0) ← **Underway**
- Positronium quantum interference, dynamics and decoherence (QUPLAS-I)
- Positronium gravitational studies (QUPLAS-II)

Method to measure g through Interference Pattern Shifts:

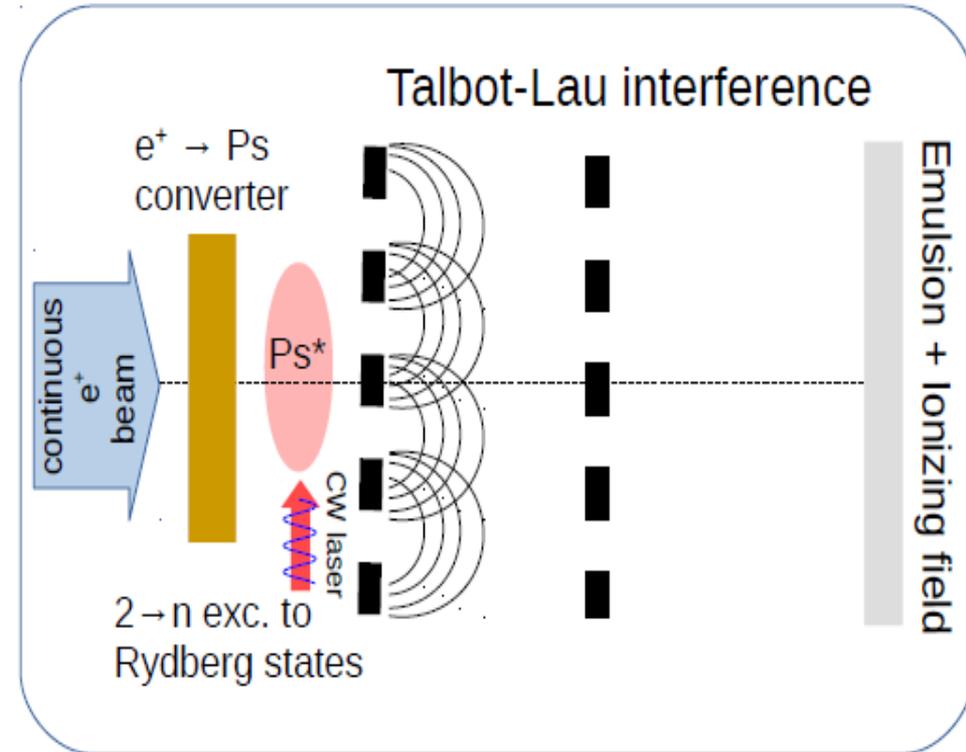
- Quantum Talbot-Lau Interferometry (pitch ~ 100 microns)

Cross-checks and systematics:

- Moiré classical deflectometry (pitch of \sim mm)
- Dynamical space-gamma method (not shown)

Assuming:

0.5 dots/s on the emulsion, 50% contrast,
 $d_3 = 476 \mu\text{m}$ (fringe period), $\Delta x = 4 \mu\text{m}$ gravity fall

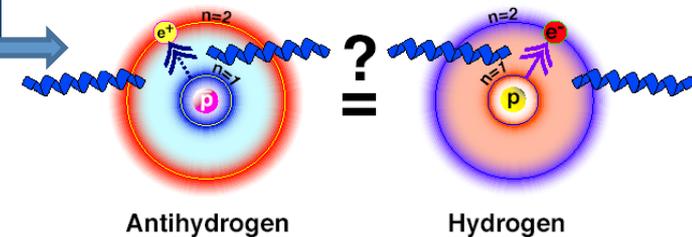


Proprietà gravitazionali dell'antimateria

Quali sono le proprietà degli anti-atomi?

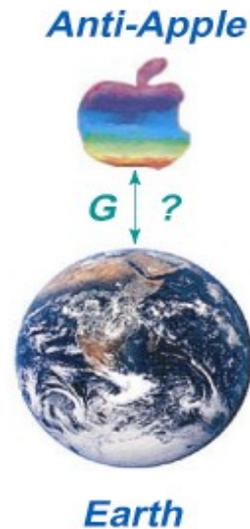
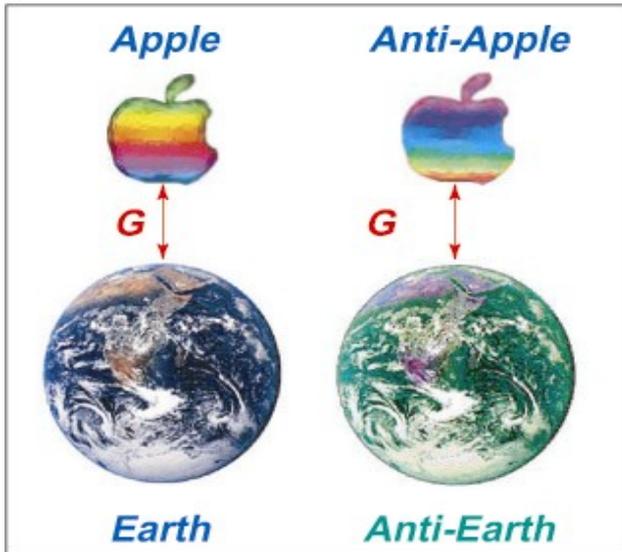
Sono fatti come gli atomi ordinari? (a parte le cariche scambiate)

Cadono come gli atomi ordinari nel campo gravitazionale terrestre?



CPT Symmetric Situation

Not:



Come cade un antiatomo?

Test di leggi fisiche fondamentali con antimateria (CPT e Principio di Equivalenza)

Premio Nobel di Fisica 2011

Saul Perlmutter, Brian P. Schmidt, Adam G. Riess

Espansione Accelerata dell'Universo

Dark energy ~ 68%

Dark matter ~ 27%

Matter ~5%

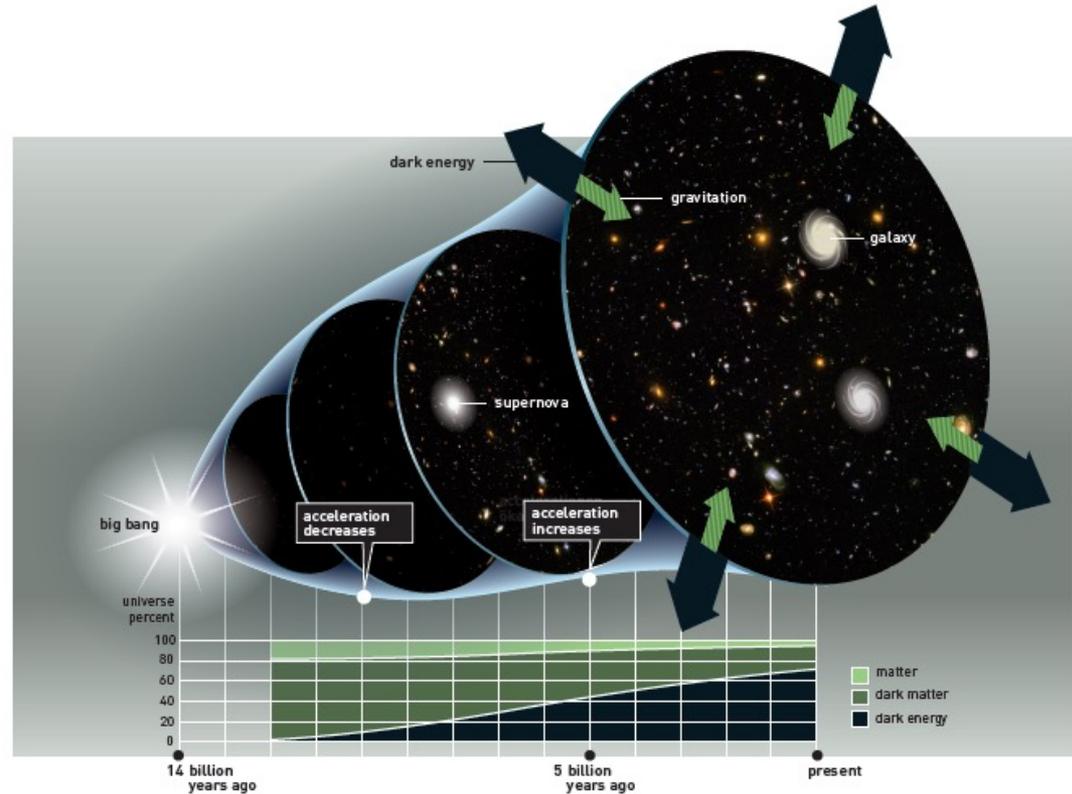
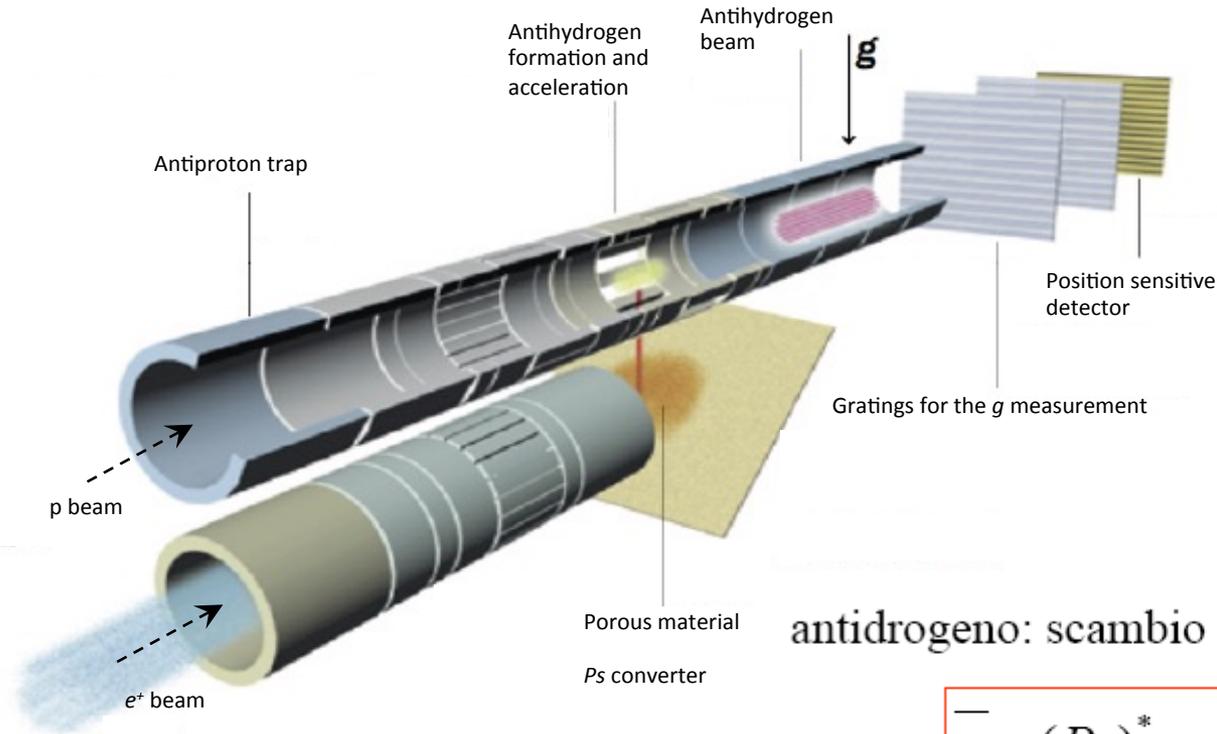


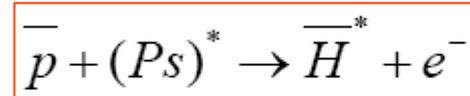
Figure 1. The world is growing. The expansion of the Universe began with the Big Bang 14 billion years ago, but slowed down during the first several billion years. Eventually it started to accelerate. The acceleration is believed to be driven by dark energy, which in the beginning constituted only a small part of the Universe. But as matter got diluted by the expansion, the dark energy became more dominant.

Può l'antigravità spiegare l'espansione accelerata dell'Universo?

AEGIS (Antimatter Experiment: Gravity, Interferometry, Spectroscopy)



antidrogeno: scambio carica con positronio



- Scopo principale: misura di g

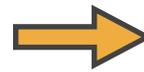
¿Cómo se mide g?



$$h = \frac{1}{2}gT^2 = \frac{g}{2}\left(\frac{L}{v_z}\right)^2$$

AEgIS realistic numbers:

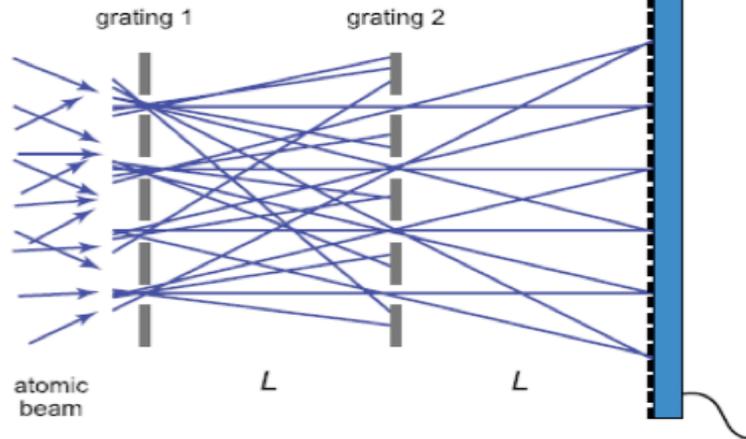
- horizontal flight path $L \sim 1$ m
- horizontal velocity $v_z \sim 500$ m/s



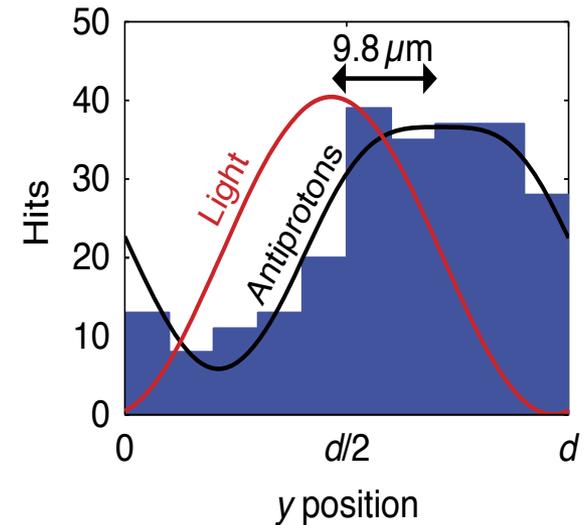
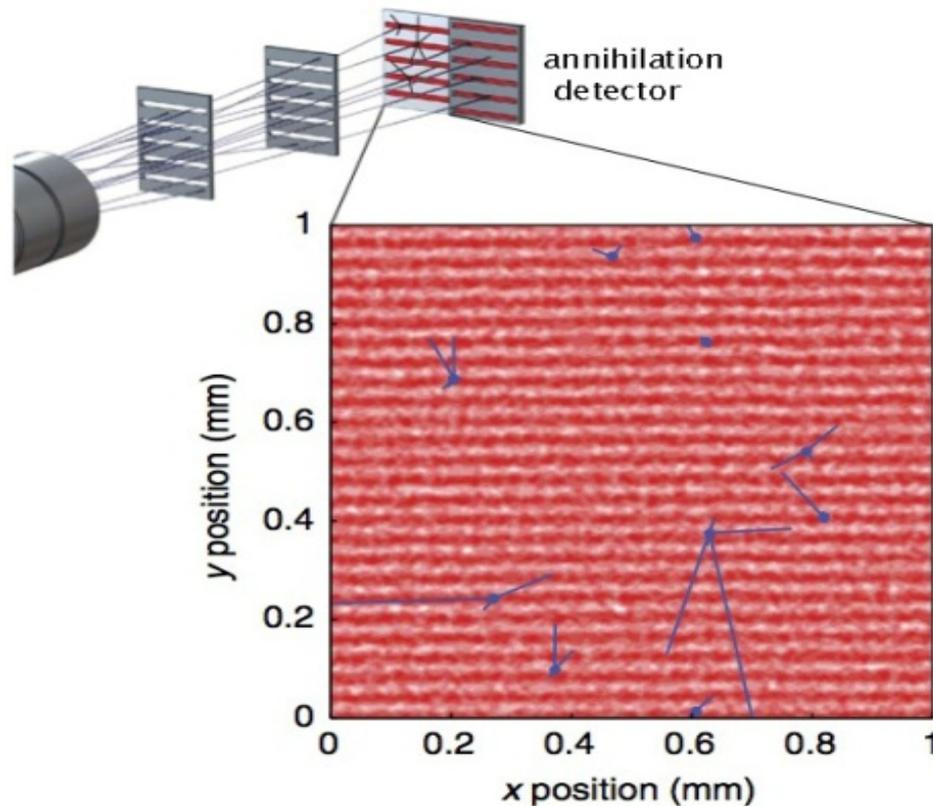
vertical deflection ~ 20

μm

position-sensitive detector



Mini deflectometro de moiré: Deflexión de un haz de antiprotones (AEgIS, CERN)



Nature Com **5**, 4538 (2014) (I.F.: **11.329**)

Single-cell analysis by means of positron annihilation spectroscopy

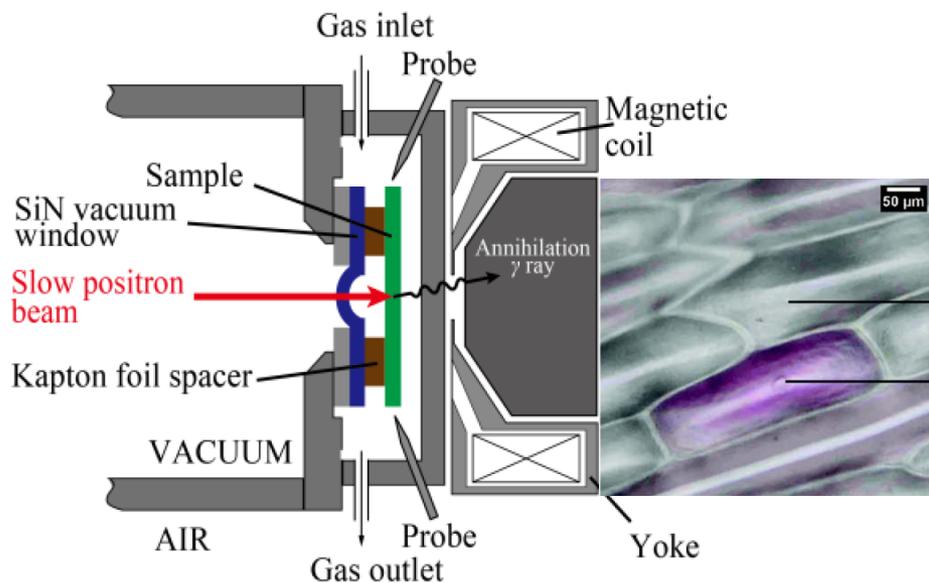
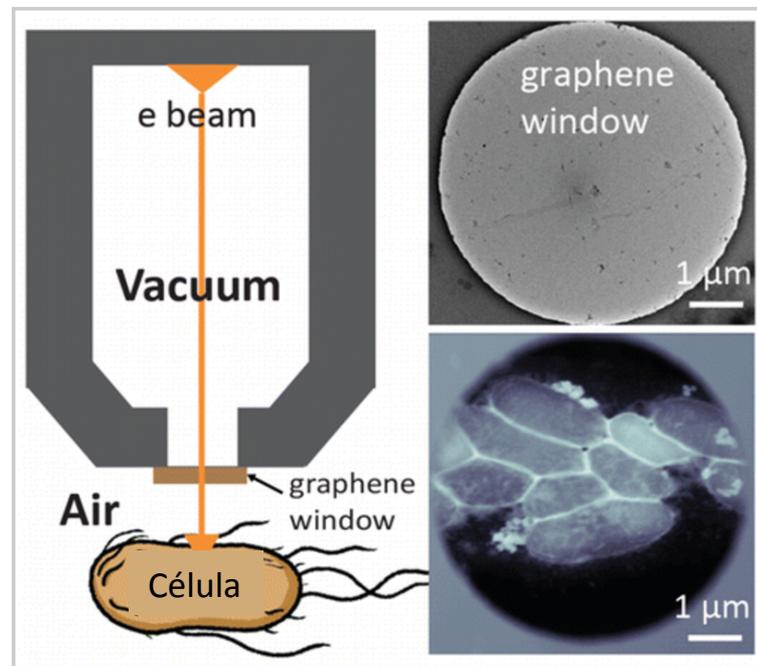


Fig. 4. Schematic illustration of the sample chamber with humidity controller (not to scale).



Nano Letters (Nov 2016)

Single-cell analysis by means of positron annihilation spectroscopy

- Dosimetría en células individuales
- Cinética del cambio químico durante la diferenciación en células madres
- Células madres tumorales
- Cambios en la membrana celular durante la respuesta de un impulso eléctrico (foto-comunicación polímero/célula)



Gracias!