

CPT Invariance and the QUPLAS Experiment

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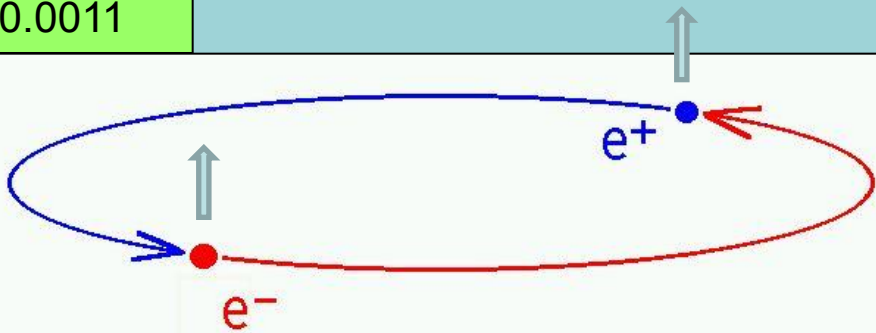


QUPLAS = QUantum interferometry and gravitation with Positrons and LASers

- System under study: positronium
- Experimental techniques: Ps beam preparation, quantum interferometry

⁰
Ps
0.0011

ortho-Ps (142 ns lifetime)



Gravitation with a Matter-Antimatter system (Positronium)

Testing CPT and the Einstein Equivalence Principle (EEP)

The QUPLAS Collaboration (as of May 2025)

Università degli Studi and INFN Milano
M. Giammarchi (spokesperson), G. Maero,
M. Romé, G. Roncoli, F. Triggiani, V. Toso

Politecnico di Milano (at Como)
M. Bayo, R. Ferragut, M. Leone,

Università di Firenze LENS and INFN
G. Rosi, L. Salvi, G. Tino, G. Vinelli

Università di Brescia and INFN Pavia
S. Migliorati, L. Venturelli

Università di Modena-Reggio and CNR Nanoscience Institute
M. Beleggia, S. Frabboni, G.C. Gazzadi, V. Grillo



Home of the Experiment: L-NESS Laboratory of the Politecnico in Como
<http://www.positron.fisi.polimi.it>

Others:

- Laboratori Nazionali del Gran Sasso
- Università and INFN Napoli
- Tohu University (Japan)

Why QUPLAS?

Expected breaking of **CPT** and **EEP** at some level because of **Planck Scale effects** (Quantum Gravity regime)

Decisive importance for the **matter content (asymmetry) of Universe**

V.A. Kostelecky and A. Vargas

Lorentz and CPT tests with hydrogen, antihydrogen and related systems

Physical Review D 92 (2015) 056002

Ps gravitation measurement at some %

$$\frac{\delta g}{g}(Ps) = \frac{8}{3} c_e$$

$$m_G = m_I = \overline{m_I} = \overline{m_G} ?$$

EEP for matter

Tested at 10^{-15} accuracy

Class. Quant. Grav. 36 (2019) 225006

CPT?

EEP?

Antimatter Interferometry



Journées de Broglie 2023
100 Years of Matter Waves
Conférence internationale du 3 au 5 juillet 2023 à Paris



From QUPLAS-0:

Positron quantum interferometry in single particle mode



To QUPLAS:

Positronium interferometry and gravitation

physicsworld Magazine | Latest | People | Impact

quantum mechanics

QUANTUM MECHANICS | RESEARCH UPDATE
Antimatter quantum interferometry makes its debut
05 May 2019 Isabelle Dumé

physicsworld **TOP 10 BREAKTHROUGH 2019**

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

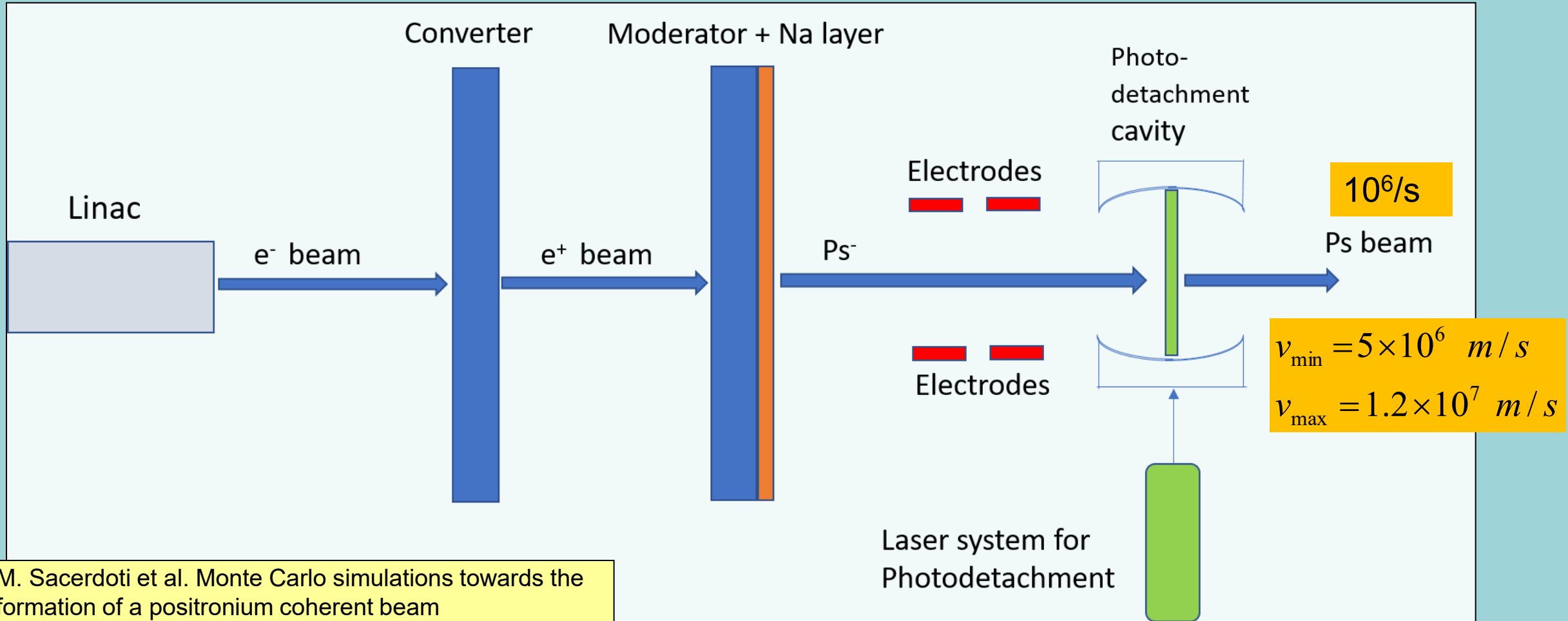
- 1) Ps Beam Preparation (neutral beam)
- 2) Ps \rightarrow Interferometer (g measurement)

1) Ps beam

Positrons

Ps Ion ($e^+ e^- e^-$)
(0.5 ns lifetime)

Ortho-Ps
(142 ns lifetime)



M. Sacerdoti et al. Monte Carlo simulations towards the formation of a positronium coherent beam
Nucl. Instr. & Methods A 1071 (2025) 170068.

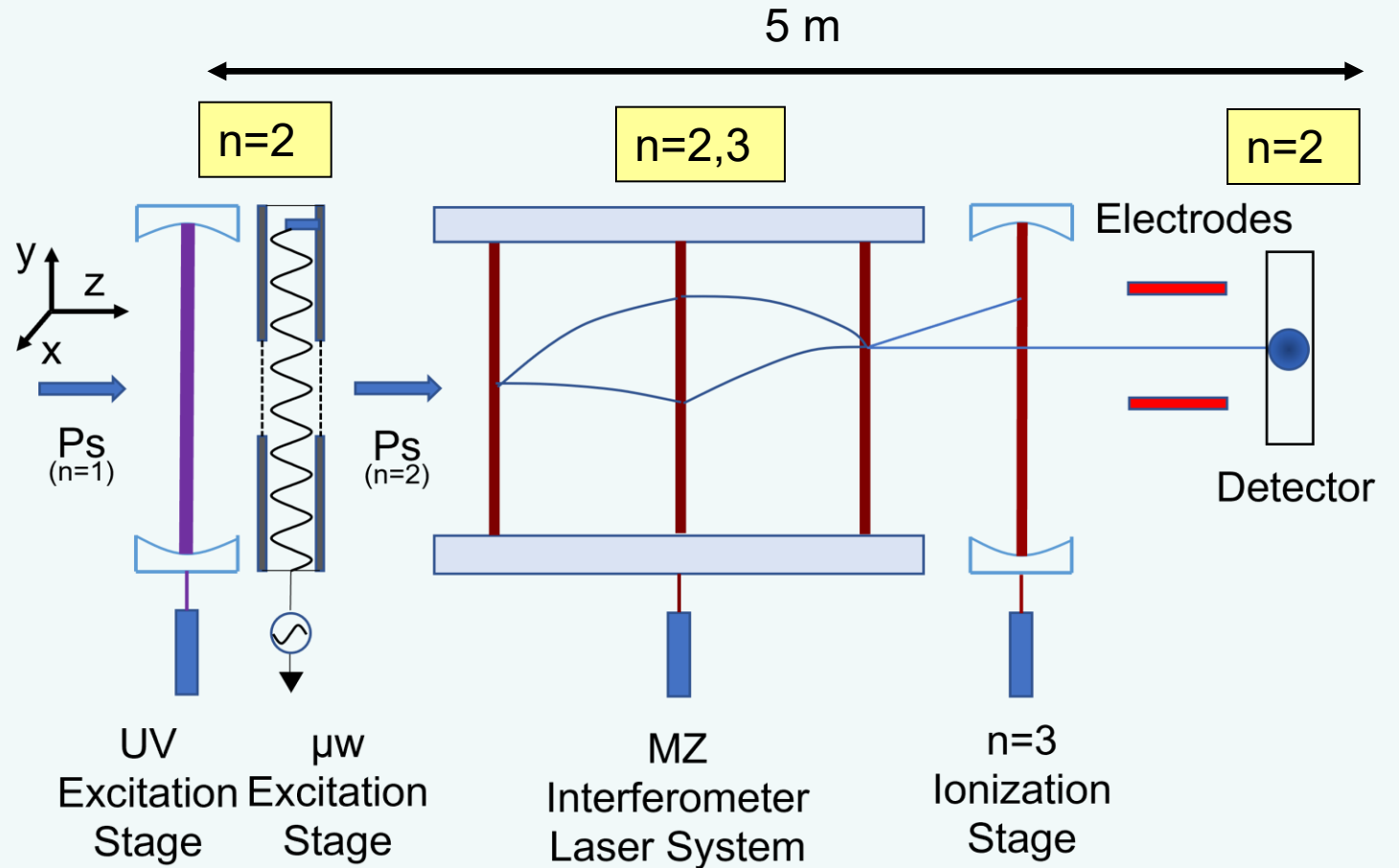
2) The LMT – Mach Zehnder Interferometer

$$\Delta\phi = k_{\text{eff}} g T^2$$

- Excitation to $n=2$ (1 μs lifetime)

- $n=2$
Two level system
- $n=3$

- Removal of $n=3$



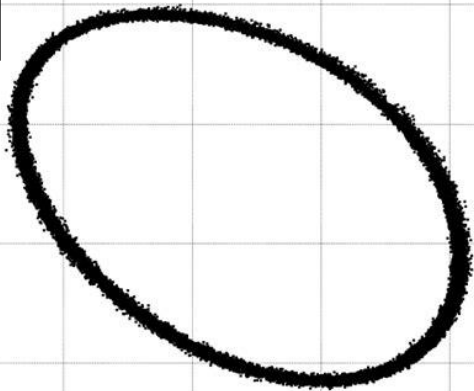
b)

G. Vinelli et al., A large-momentum-transfer matter-wave interferometer to measure the effect of gravity on positronium
Classical and Quantum Gravity 40 (2023) 205024.

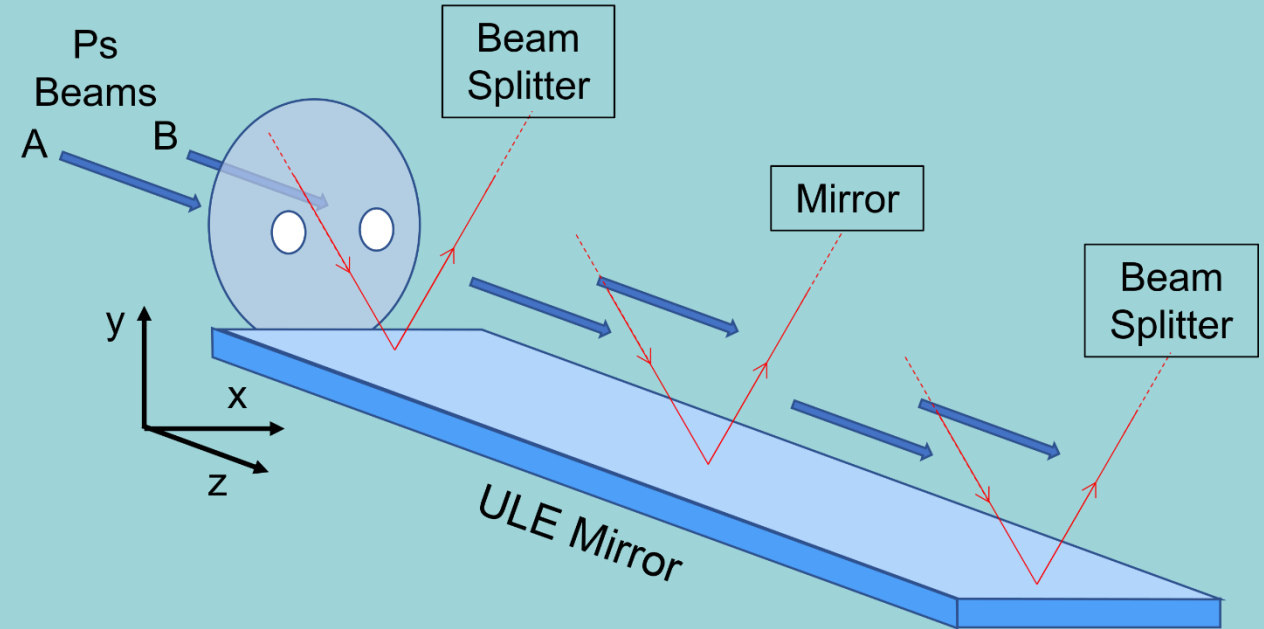
Extraction of the g-induced phase
(double split Ps- beams)

$$\Delta\phi = \pm k_{eff} g T^2$$

Population
on beam 1



Population on beam 2



Differential scheme: cancellation of k-dependent noise
(and other common-mode noise sources)

Same technique used in testing the EEP with Rb atoms

G. Rosi et al, Nat. Comm. 10.1038/ncomms15529

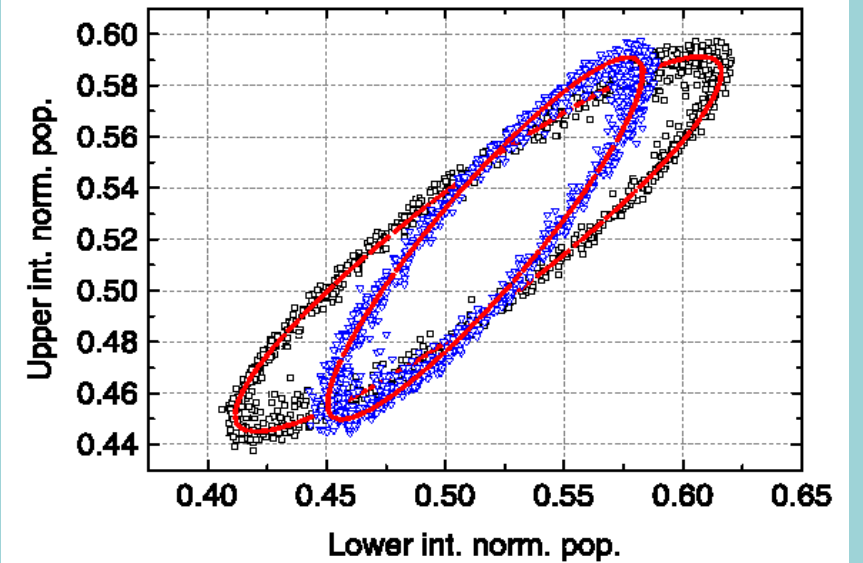
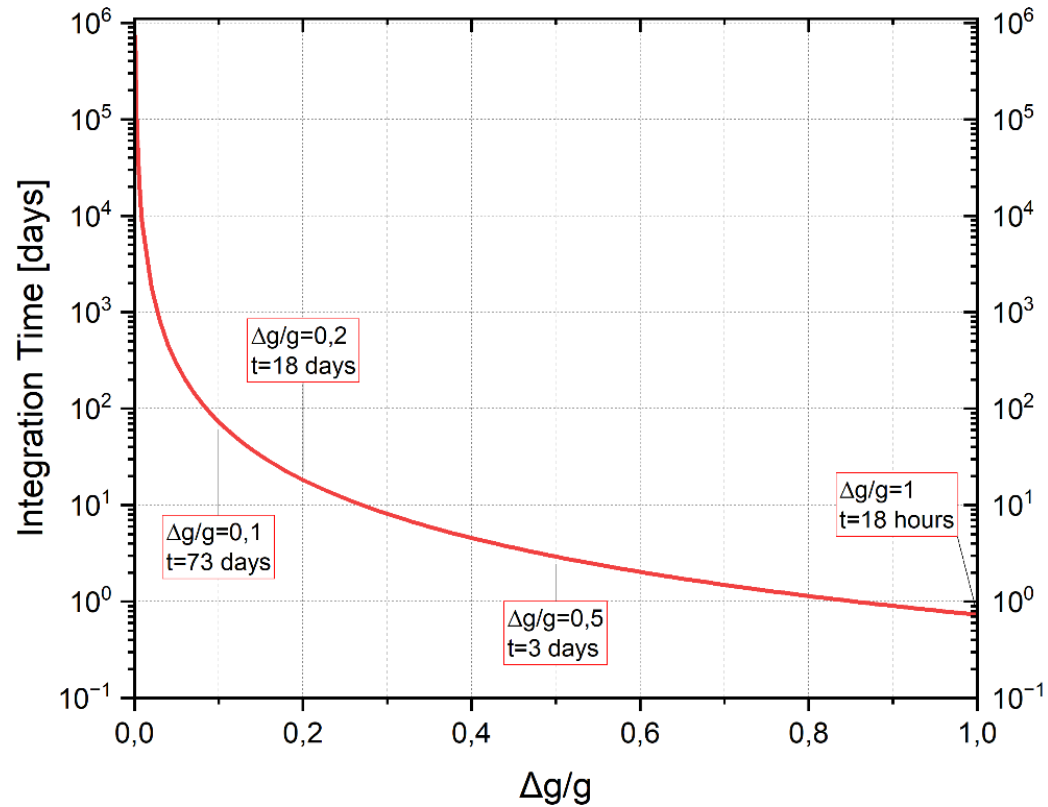
Systematics and Sensitivity

Double differential measurement (for systematics studies)

- Two beams (beam split) Lissajous1
- Two (or more) velocities Lissajous2

$$v_{\min} = 5 \times 10^6 \text{ m/s}$$

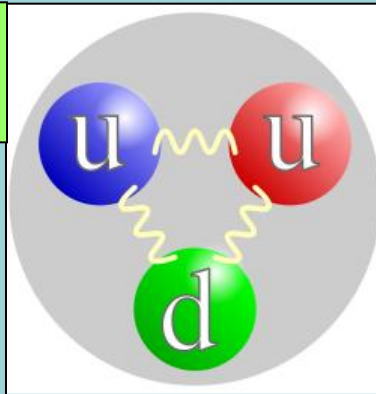
$$v_{\max} = 1.2 \times 10^7 \text{ m/s}$$



Why QUPLAS?
(strikes back!)

Positronium mass made Standard
Model fundamental particles masses
(contrary to antiproton)

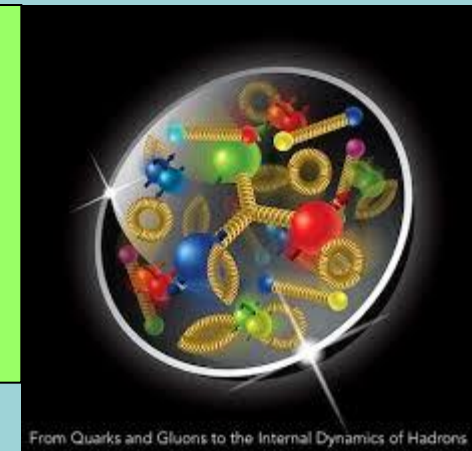
What people think
hadrons are



What hadrons really
are

Color field

Bare masses



Observation of the effect of gravity on the motion of antimatter

[E. K. Anderson](#), [C. J. Baker](#), [W. Bertsche](#) , [N. M. Bhatt](#), [G. Bonomi](#), [A. Capra](#), [I. Carli](#), [C. L. Cesar](#), [M. Charlton](#), [A. Christensen](#), [R. Collister](#), [A. Cridland Mathad](#), [D. Duque Quiceno](#), [S. Eriksson](#), [A. Evans](#), [N. Evetts](#), [S. Fabbri](#), [J. Fajans](#) , [A. Ferwerda](#), [T. Friesen](#), [M. C. Fujiwara](#), [D. R. Gill](#), [L. M. Golino](#), [M. B. Gomes Gonçalves](#), ... [J. S. Wurtele](#)  Show authors

[Nature](#) **621**, 716–722 (2023) | [Cite this article](#)

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$(0.75 \pm 0.13$ (statistical + systematic) ± 0.16 (simulation)) g

Thank you for your attention

