Positronium our Spy to the Mirror World

Paolo Crivelli

ETH Zurich

Positron in Astrophysics, Mürren, March 21, 2012

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Symmetries

Essential role in physics

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Invariance under given continous or discrete trasformations => associated conserved quantities (Noether's theorem), e.g.:

- Space-time translation invariance <=> energy-momentum conservation
- Rotation invariance <=> angular momentum conservation

- Gauge invariance <=> Charge conservation

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In modern "relativistic" theories the Lorentz group is fundamental.

Proper Lorentz transformations (rotation and boost)

Boost
e.g. along x
$$\Lambda^{\mu}{}_{\nu} = \begin{bmatrix} \gamma & -\beta\gamma & 0 & 0 \\ -\beta\gamma & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Proper L.T.

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Proper L.T.

Without them we could not characterize particles by their rest mass!

Improper Lorentz transformations (time and space reflections)

Reflection,
e.g. space
$$\Lambda^{\mu}{}_{\nu} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \longrightarrow P: \begin{cases} \dot{x} \rightarrow -\dot{x} \\ t \rightarrow t \\ P: \begin{cases} \dot{x} \rightarrow -\dot{x} \\ t \rightarrow t \\ Parity \end{cases} P^{2} = 1$$

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What about them?

Mirror symmetry (parity) violation



Parity violation in in weak interaction.

T.D. Lee and C.N. Yang, Phys. Rev. 104, 4 (1956) C.S. Wu et al., Phys. Rev. 105, 1413 (1957) R.L.Garwin, L.M.Lederman, M.Weinrich, Phys. Rev. 105, 1415 (1957)

Mirror symmetry (parity) violation





W. Pauli in a letter to V. Weisskopf, "Now after the first shock is over, I begin to collect myself. Yes, it was very dramatic."

In the standard model this effect is introduced from the beginning in the Lagrangian.

$$\begin{pmatrix} \nu_l \\ l^- \end{pmatrix}_L, \quad l_R^-, \quad \begin{pmatrix} u \\ d \end{pmatrix}_L, \quad u_R, \quad d_R$$

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Is nature really left-right asymetric or do we happen to live in a universe dominated by particles with such properties?

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Left-right symmetric models, symmetry restored at higher energies (V+A suppressed by heavy W_R mass) Pati and Salam, Phys. Rev. D10, 275 (1974) Mohapatra and Pati, Phys. Rev. D11, 566 (1975), Senjanovic and Mohapatra, D12, 1502 (1975)

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Postulation of the existence of a sector of mirror particles

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The mirror world



For recent review see,Okun, Phys.Usp. 50 (2007) 380-389 [hep-ph/0606202] and Ciarcelluti,Int.J.Mod.Phys.D19:2151-2230 (2010).

> If such a sector of particle exists -> mirror symmetry conserved -> left-right symmetry of nature restored

> > Kobzarev&Okun&Pomeranchuk, Blinnikov&Khlopov, Foot, Berezhiani, Mohapatra

Mirror sector



Mirror particles:

→ Same properties of the ordinary particles but chirality of the fields inversed.

→ Same micro-physics governs the interactions among the mirror particles but they experience V+A weak interaction.

Mirror sector



The mirror sector would interact through gravitation with us. \rightarrow Mirror particles are very good dark matter candidates.

Mirror sector



The mirror sector could interact through photon mirror-photon kinetic mixing: B. Holdom, Phys. Lett. B166, 196 (1986) \rightarrow Implications for cosmology. \rightarrow Bounds (LSS, CMB, BBN): $\varepsilon < \text{few } 10^{-9}$. Z. Berezhiani, A. Lepidi, Phys. Lett.B 681, 276 (2009) P. Ciarcelluti, R. Foot, Phys. Lett.B 679, 278 (2009)

Mirror matter & Ps

The mirror matter could have a portal to our world through photonmirror photon mixing (ϵ). S. L. Glashow, Phys. Lett. B167, 35 (1986)



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Aerogel experiment



Aerogel experiment

A. Badertscher, P. Crivelli et al., Phys. Rev. D. 75, 032004 (2007)

Aerogel target, SiO₂ grains 5-10 nm



Collisions with matter destroy the coherence of oscillation suppressing the o-Ps - o-Ps' conversion.



New vacuum experiment

 \rightarrow Br(oPs \rightarrow invisible) < 4 x10⁻⁸ \rightarrow factor 10 improvement (statistics)

 \rightarrow Mixing strength ε <1 x10⁻⁹ \rightarrow factor 100 improvement

(Ps mean free path in a vacuum cavity: 30 mm $\rightarrow \Gamma_{coll}$ 10⁴ smaller) *P.Crivelli et al., JINST 5, P08001 (2010)*

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Confront interpretation of DAMA/LIBRA and CoGeNT annual signal modulation and CRESST excess as generated by elastic scattering of mirror matter $\rightarrow \epsilon \approx 1 \times 10^{-9}$

R. Foot., Phys.Lett. B703, 7 (2011)

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R. Foot., Phys.Lett. B703, 7 (2011)

Cross check: change Ps velocity ~ Γ_{coll} Number of signal 2 times smaller without affecting the background!

P. Crivelli et al., Phys. Rev. A. 81, 052703

Experimental setup



Production of positronium in vacuum

High efficiency gamma detector



Experimental setup



Modify geometry of the detector to accommodate the beam pipe => no direct way for the annihilation photons to escape detection

Positron tagging

Thin Carbon foils (15-20 nm) confine Ps in the vacuum cavity and enhance the confidence level of the trigger beam.



The keV positrons can go through while even the most energetic Ps atoms are blocked

Positron tagging



Positron tagging



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Time (ns)

Summary/Outlook

All the main parts for the experiment are available (beam, calorimeter, DAQ), the tagging system has been tested. *P.Crivelli et al., JINST 5, P08001 (2010)*

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No major investement is required but man power is needed (unfortunately at the moment no funding).

Thank you very much for your attention!

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