Testing quantum gravity with muons

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Warszawa, December 10, 2019

The paper

Physics Letters B 794 (2019) 41–44

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

A bound on Planck-scale deformations of CPT from muon lifetime

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A R T I C L E I N F O

Article history:
Received 24 April 2019
Received in revised form 14 May 2019
Accepted 16 May 2019
Available online 21 May 2019
Editor: M. Cvetič

Keywords:
CPT symmetry
Quantum gravity
κ-deformation
Particle lifetime

A B S T R A C T

We show that deformed relativistic kinematics, expected to emerge in a flat-spacetime limit of quantum gravity, predicts different lifetimes for particles and their antiparticles. This phenomenon is a consequence of Planck-scale modifications of the action of discrete symmetries. In particular we focus on deformations of the action of CPT derived from the κ-Poincaré algebra, the most studied example of Planck-scale deformation of relativistic symmetries. Looking at lifetimes of muons and anti-muons we are able to derive an experimental bound on the deformation parameter of $\kappa \gtrsim 4 \times 10^{14}$ GeV from measurements at the LHC. Such bound has the potential to reach the value of $\kappa \gtrsim 2 \times 10^{16}$ GeV using measurements at the planned Future Circular Collider (FCC).

"Quantum Gravity"

- 'Quantum Gravity' in the title are not just buzzwords.
- We don't know what quantum gravity theory is, and, so far, we do not have any clear experimental signal of quantum gravity origin.
- But we have some intuitions what might be possible quantum gravity effects; for example, it is a basically model independent prediction that spacetime becomes non-commutative when QG effects are relevant.
- We can consider specific models with spacetime non-commutativity, find their prediction, and hopefully confront them with experiments.

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Deformed symmetries

- As it happens, the spacetime non-commutativity is sometimes not (naively) Lorentz-covariant.
- For example, in the model called κ-Minkowski we have

$$\left[x^0, x^i\right] = \frac{\imath}{\kappa} x^i \,, \qquad \text{with } \kappa \backsimeq \text{Planck energy}$$

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Deformed minus

- In the standard case, the discrete symmetries action, replaces particle with momentum **p** with (anti) particle with momentum $-\mathbf{p}$. This is OK, because the mass shell relation is insensitive to this, and it follows, that particles and antiparticles have the same rest mass.
- In quantum deformed case the minus is replaced by a nonlinear operation, called the antipode $S(\mathbf{p})$.

$$S(E) = -E + \frac{p^2}{\kappa} + \dots, \quad S(\mathbf{p}) = -\mathbf{p}\left(1 - \frac{E}{\kappa}\right) + \dots$$

- It preserves the mass-shell condition

$$E^2 - \mathbf{p}^2 = m^2 \iff S(E)^2 - S(\mathbf{p})^2 = m^2$$

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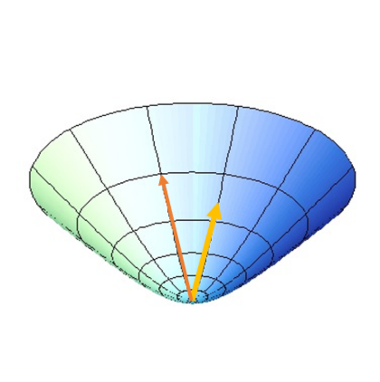
Deformed minus

- As a result, in the deformed case, under the action of CPT the particle particle with momentum $\mathbf{p}$ becomes the anti-particle with momentum $-S(\mathbf{p})$. It is an important property of deformed theory that the action of Lorentz boosts on particles and antiparticles is not identical.



Decay probabilities

- It follows that although the decay rates of particles and antiparticles (as measured in the rest frame) are perfectly identical, for moving of particles and antiparticles decay probabilities are slightly different.

$$\Gamma_{part} = \Gamma \frac{E}{m} \exp\left(-\Gamma t \frac{E}{m}\right),$$

$$\Gamma_{apart} = \Gamma \left(\frac{E}{m} - \frac{\mathbf{p}^2}{\kappa m}\right) \exp\left(-\Gamma t \left(\frac{E}{m} - \frac{\mathbf{p}^2}{\kappa m}\right)\right)$$

Bounds

- In the case of LHC muons one obtains the following bound on the parameter of deformation

$$\kappa \gtrsim 4 \times 10^{14}\ \text{GeV}$$

- This is still five order of magnitudes less than the expected Planck mass $M_{Pl} \approx 1.2 \times 10^{19}$ GeV, but it is hoped that this bound can be improved with the help of a more dedicated setup.