Test of the Realism in Particle Physics

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Introduction

In current work 3-time-dependent Wigner inequalities, based on the Realism [1], are tested.

Realism

- **Classical Realism [2]**
  A set of all physical characteristics (in classical terms) of a system exists jointly and is independent of an observer, even if the observer cannot simultaneously measure these characteristics with any classical measurement device.
- **Locality [2]**
  If two measurements which were performed inspatially-separated points of the spacetime then the readings of one classical device do not affect the readings of a second one in any way.
- **No-signaling in time**
  A measurements does not change the statistics of possible outcomes of the next measurements.
- **Freedom of choice [2]**
  The observer can freely choose any experimental parameters from the available ones.

3-time-dependent Wigner inequalities [1]

$$
\begin{aligned}
& \omega\left(a_+^{(2)}(t_2)\cap b_+^{(1)}(t_1)\right) \leq \\
\leq\ & \omega\left(a_+^{(2)}(t_0)\to a_+^{(2)}(t_2)\right)\left(\omega\left(b_+^{(1)}(t_0)\to b_+^{(1)}(t_1)\right)+\omega\left(b_-^{(1)}(t_0)\to b_+^{(1)}(t_1)\right)\right)\omega\left(a_+^{(2)}\cap c_+^{(1)},t_0\right) \\
+\ & \omega\left(a_-^{(2)}(t_0)\to a_+^{(2)}(t_2)\right)\left(\omega\left(b_+^{(1)}(t_0)\to b_+^{(1)}(t_1)\right)+\omega\left(b_-^{(1)}(t_0)\to b_+^{(1)}(t_1)\right)\right)\omega\left(a_-^{(2)}\cap c_+^{(1)},t_0\right) \\
+\ & \omega\left(b_+^{(1)}(t_0)\to b_+^{(1)}(t_1)\right)\left(\omega\left(a_+^{(2)}(t_0)\to a_+^{(2)}(t_2)\right)+\omega\left(a_-^{(2)}(t_0)\to a_+^{(2)}(t_2)\right)\right)\omega\left(c_+^{(2)}\cap b_+^{(1)},t_0\right) \\
+\ & \omega\left(b_-^{(1)}(t_0)\to b_+^{(1)}(t_1)\right)\left(\omega\left(a_+^{(2)}(t_0)\to a_+^{(2)}(t_2)\right)+\omega\left(a_-^{(2)}(t_0)\to a_+^{(2)}(t_2)\right)\right)\omega\left(c_+^{(2)}\cap b_-^{(1)},t_0\right)
\end{aligned}
$$

Graph description

A_6 :
$a_+ \to M_1, a_- \to M_2,$
$b_+ \to M, b_- \to \bar{M},$
$c_+ \to M_L, c_- \to M_H.$

A_8 :
$a_+ \to M_1, a_- \to M_2,$
$b_+ \to \bar{M}, b_- \to M,$
$c_+ \to M_L, c_- \to M_H.$

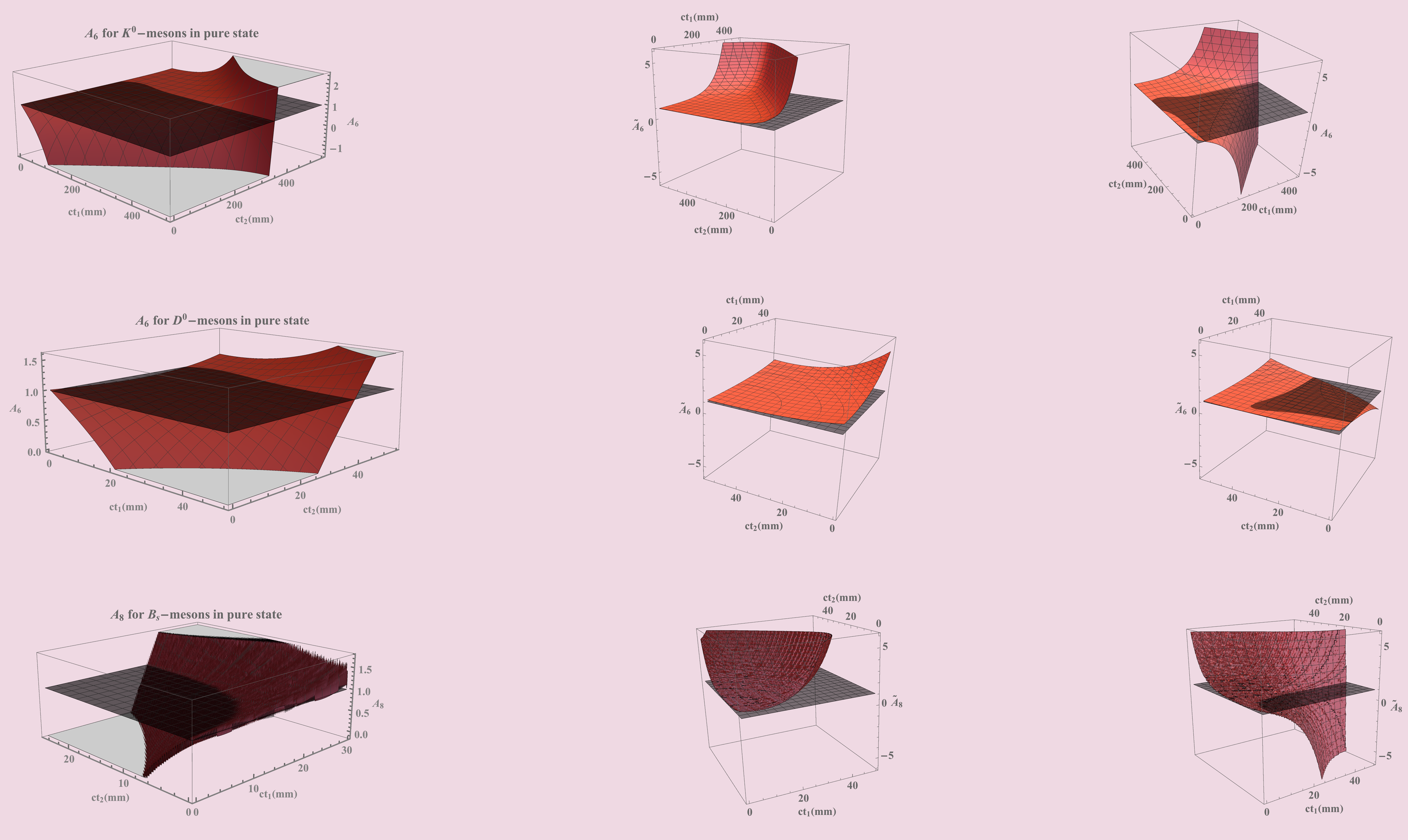
A - for Pure state, $\tilde{A}$ - for Werner state
I column: Graphs for Bell pure state (x=1)
II column: Graphs for Werner state with x=0.3
III column: Graphs for Werner state with x=0.7

Graphs

K^0-mesons

D^0-mesons

B_s-mesons



Considered bases [4]

1. Flavour basis:

$|\,M\,\rangle, |\,\bar{M}\,\rangle$, M-meson, for example, $|\,K^0\,\rangle = |\,d\bar{s}\,\rangle$.

M and $\bar{M}$ have not certain CP eigenvalues.
2. Basis with certain CP

$$|\,M_1\,\rangle = \frac{|\,M\,\rangle + e^{i\phi}\,|\,\bar{M}\,\rangle}{\sqrt{2}},$$
$$|\,M_2\,\rangle = \frac{|\,M\,\rangle - e^{i\phi}\,|\,\bar{M}\,\rangle}{\sqrt{2}}.$$

3.Basis with certain mass and lifetime

$$|\,M_L\,\rangle = p\left(|\,M\,\rangle + e^{i\phi}\frac{q}{p}\,|\,\bar{M}\,\rangle\right),$$
$$|\,M_H\,\rangle = p\left(|\,M\,\rangle - e^{i\phi}\frac{q}{p}\,|\,\bar{M}\,\rangle\right),$$

where $|p|^2+|q|^2=1$, $|p|^2-|q|^2=F$.
In this work $F=0$ and $|p|^2=|q|^2=\frac{1}{2}$.

Then following dscription is possible: $\frac{p}{q}=e^{i\xi}$, where parameter ξ was measured experimentally.

It is very convenient to consider evolution in this basis:

$$|\,M_L(t)\,\rangle = e^{-im_Lt-\Gamma_Lt/2}\,|\,M_L\,\rangle,$$

$$|\,M_H(t)\,\rangle = e^{-im_Ht-\Gamma_Ht/2}\,|\,M_H\,\rangle, \quad \text{где } t_0=0.$$

Inequalities are tested on Bell pure state Ψ^-:

$$|\,\Psi^-\,\rangle = \frac{1}{\sqrt{2}}(|\,M\,\rangle\,|\,\bar{M}\,\rangle - |\,\bar{M}\,\rangle\,|\,M\,\rangle).$$

And on Werner state [5]:

$$\hat{\rho}^{(W)} = x\,|\,\Psi^-\,\rangle\langle\,\Psi^-\,| + \frac{1}{4}(1-x)\hat{1},$$

where x - purity parameter, $0\leq x\leq 1$,
$\hat{1}$ - identity matrix.

Conclusion

1. Time-dependent Wigner inequalities are more preferable for experimental testing that time-independent [6];

2. Correct 3-time-dependent Wigner inequality derivation based on Realism was made;

3. It was shown that 3-time-dependent Wigner inequalities can be violated in case of A_6 for K^0- and D^0- mesons and in case of A_8 for B_s-mesons;

4. This inequalities were tested for Werner state and it was shown that their violations can be experimentally observed if background is less than 50%.

References

[1] N. Nikitin, K. Toms, Phys. Rev. D 95, 052103 (2017).
[2] A. Einstein, B. Podolsky and N. Rosen, Phys. Rev. 47, 777 (1935).
[3] E. P. Wigner, Am. J. Phys. 38, 1005 (1970).
[4] F. Uchiyama, Phys. Lett. A 231, 295 (1997).
[5] R. F. Werner, Phys. Rev. A 40, 4277–4281 (1989).
[6] A. Efimova, J. Phys. Conf. Ser. 1439, 012008 (2020).