Entangled state of two neutral kaons in KLOE-2 experiment

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KLOE experiment

A system of two neutral kaons

CPT

KLOE-2
Entangled state of two neutral kaons in KLOE-2 experiment
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e^+ − e^- collisions with \( E_{CM} = 1020 \text{ MeV} \) - \( \phi \) meson resonance centre

- main \( \phi \) decay modes:

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>BR (%)</th>
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<tbody>
<tr>
<td>( K^+ K^- )</td>
<td>49.1</td>
</tr>
<tr>
<td>( K^0 \bar{K}^0 )</td>
<td>33.8</td>
</tr>
<tr>
<td>( \rho \pi + \pi^+ \pi^- \pi^0 )</td>
<td>15.6</td>
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<tr>
<td>( \eta \gamma )</td>
<td>1.26</td>
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</tbody>
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Neutral kaons can be described in different bases depending on the features one wants to describe:

- the basis of strangeness eigenstates: $K^0$, $\bar{K}^0$;
- the basis of Hamiltonian eigenstates: $K_S$, $K_L$ - well defined lifetimes:

$$|K_S\rangle = \frac{1}{\sqrt{2 \left(1 + |\epsilon_S|^2\right)}} \left[ (1 + \epsilon_S) |K^0\rangle + (1 - \epsilon_S) |\bar{K}^0\rangle \right] ,$$

$$|K_L\rangle = \frac{1}{\sqrt{2 \left(1 + |\epsilon_L|^2\right)}} \left[ (1 + \epsilon_L) |K^0\rangle - (1 - \epsilon_L) |\bar{K}^0\rangle \right] ;$$

- (historically) the basis of $CP$ operator eigenstates: $K_1$, $K_2$
As $P$ and $C$ eigenvalues are conserved in strong processes, the initial state of two neutral kaons coming from $\phi$ meson decay has to be:

$$|i\rangle = \frac{1}{\sqrt{2}} \left\{ |K^0 (-\vec{p})\rangle |\bar{K}^0 (+\vec{p})\rangle - |\bar{K}^0 (-\vec{p})\rangle |K^0 (+\vec{p})\rangle \right\} = \frac{N}{\sqrt{2}} \left\{ |K_S (+\vec{p})\rangle |K_L (-\vec{p})\rangle - |K_L (+\vec{p})\rangle |K_S (-\vec{p})\rangle \right\}$$

$z\ N \approx 1.$

- possibility of testing EPR-like phenomena
Double decay rate for decays to the same final states:

\[ I(f_1, f_2; \Delta t) = \frac{C_{12} |\eta|^2}{\Gamma_S + \Gamma_L} \left\{ e^{-\Gamma_L \Delta t} + e^{-\Gamma_S \Delta t} - 2e^{-\frac{\Gamma_S + \Gamma_L}{2} \Delta t} \cos(\Delta m \Delta t) \right\} \]
CPT theorem assumptions:

- Lorentz invariance
- unitarity
- locality
Possibility of $CPT$ nonconservation connected with unitarity criterion:

- black holes can emit particles (Hawking)
- possibility of evolution of pure states into mixed states close to black holes (part of the system falls behind the event horizon)
- description of the state in the future - sum over all possible black hole states
- such evolution from pure to mixed state is incompatible with $CPT$ invariance (Wald)
- similar transitions may also be possible on a microscopic (elementary particle) level
Schematic view of KLOE-2 upgrades in the vicinity of the interaction point:
Thank you for your attention