Test of the exponential decay law at short decay times using tau leptons

The OPAL Collaboration
first: quantum theory

FAPR

its an exponential! (Bell)

But, recently-

Hidden Variable theory ... (Bohm-Bub)

its NOT an exponential!

hv theory →
Time evolution of unstable quantum states
and a resolution of Zeno's paradox

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The time evolution of quantum states for unstable particles can be conveniently divided into three domains: the very short time where Zeno's paradox is relevant, the intermediate interval where the exponential decay holds more or less, and the very long time where the decay is governed by a power law. In this work, we reexamine several questions relating to the deviations from the simple exponential decay law. On the basis of general considerations, we demonstrate that deviations from exponential decay near $t = 0$ are inevitable. We formulate general resonance models for the decay. From analytic solutions to specific narrow-width models, we estimate the time parameters $T_1$ and $T_2$, separating the three domains. The parameter $T_1$ is found to be much much less than the lifetime $\Gamma^{-1}$, while $T_2$ is much greater than the lifetime. For instance, for the charged pion decay, $T_1 = 10^{-14}/\Gamma$ and $T_2 = 100/\Gamma$. A resolution of Zeno's paradox provided by the present consideration and its limitations are discussed.
1. QM: fundamental? is a collapse really random? (SC, decay...)

2. Possibility?
   QM = description of some thermodynamical equilibrium (PV = nRT, ...)

3. Equilibrium time?
   Quantum statistical average produced in \(10^{-13}\) sec? ? ?

Collapse = general wave function is localized (made determinate) in the space of the variable which is measured.

i.e. collapse is induced by any measurement that gives a definite value to some quantity.
Some formalism (Bohm-Bub example) \[ |\psi\rangle = a_1 |\uparrow\rangle + i a_2 |\downarrow\rangle \]

'Dual Hilbert space'

\[ |\psi\rangle = \varepsilon_1 |\uparrow\rangle + \varepsilon_2 |\downarrow\rangle \]

Hidden space

\[ R_1 = \frac{|a_1|^2}{|\varepsilon_1|^2} \quad R_2 = \frac{|a_2|^2}{|\varepsilon_2|^2} \]

\[ a_1 = \frac{a_2}{\varepsilon_1} \quad R_1 > R_2 \]

Equations of motion (during a collapse):

\[ 0 < \frac{da_1}{dt} = \kappa (R_2 - R_1) a_1 |a_1|^2 \quad \frac{da_2}{dt} = \kappa (R_2 - R_1) a_2 |a_1|^2 < 0 \]

**EXPERIMENT:**

Non-uniform dist. ...

Uniform distribution

\[ \text{never realized!} \]
parameter fits $\rightarrow$ 3 parameter fits

\[ L \]

Likelihood function

\[ L = \prod G(s_i) - E \prod G(s_i) \]

Error distribution - bin correlation

\[ D = \text{EXCESS} \] relative to the # of events in the exponential form.

Comments:

A search for time dependent branching ratios!

1. total inclusive
2. 3-prong
3. 1-prong
\[ \text{experiment?} \]

\[ \text{\( \Lambda \rightarrow G \rightarrow 2 \times \text{decay vertex} \rightarrow Z \rightarrow \ldots \)} \]

\( \text{(also interaction vertex)} \)

**assumptions:**

a. decay vertex is a \( \bar{B} - B \) type collapse.
b. I decay - II decay: same \( h_{\nu} \),

\[ \frac{Z}{\nu} \rightarrow Z + \ldots \]

**expected observations:**

second 50-70 dev. → second decay dev. (i.e. BR)

\( \text{first look} \)

**motivations:**

1. "new physics" \( \Xi \) \( h_{\nu} \) time dependent BR, Aharonov

2. new direction of attack -
   - discover biasing sources!
   - misaligned detector:
   - biasing analysis (cuts…)
   - inaccurate error estimation.
   - uncontrolled background.

3. real lifetime method:
   - not take into account artificial deviations in by)
   - not by shift to the exponential
- What did we do:

* capability to detect:
  - MC (D was introduced)
  - fake zero lifetime Z's (MH)

* Bg checks

* Data $q_2 + q_2$
  - 15000 $|\cos \theta_{beam}| < 0.85$
  - 1 silicon hit + fit prob. > 0.1%
  - Vertex $\chi^2$ prob. > 5%
  - decay length [-15, +25 mm]
  - $\delta_0 < 3 \text{ mm}$

\[ 5843 \text{ Taus} \]
Systematics

* Angular Dependence

<table>
<thead>
<tr>
<th>Running period</th>
<th>92, 4 - 4 optics</th>
<th>92, 8 - 8 optics</th>
<th>93, 8 - 8 optics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-parameter fit (D in %)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-like events</td>
<td>6.7 ± 2.5</td>
<td>7.2 ± 4.5</td>
<td>0.2 ± 1.8</td>
</tr>
<tr>
<td>V-like events</td>
<td>0.6 ± 1.9</td>
<td>0.7 ± 3.5</td>
<td>3.8 ± 1.7</td>
</tr>
</tbody>
</table>

* S one dim. fit

* Beam Spot position 50μm ± 50μm

* θγ

Summary of systematic uncertainties

<table>
<thead>
<tr>
<th>Cause</th>
<th>Uncertainty</th>
<th>Correction to shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular dependence</td>
<td>± 3.2 %</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Uncertainty in S</td>
<td>± 1.2 %</td>
<td>0.0 %</td>
</tr>
<tr>
<td>Beam spot position</td>
<td>± 0.5 %</td>
<td>+0.5 %</td>
</tr>
<tr>
<td>Remaining background</td>
<td>± 0.25 %</td>
<td>-0.25 %</td>
</tr>
<tr>
<td>Total</td>
<td>± 3.5 %</td>
<td>0.25 %</td>
</tr>
</tbody>
</table>
Results

Real data

<table>
<thead>
<tr>
<th>Fit method</th>
<th>Maximum Likelihood</th>
<th>Binned $\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Events</td>
<td>5843</td>
<td>5843</td>
</tr>
</tbody>
</table>

2 parameter fit

| L (mm) | 2.219 ± 0.030 | 2.188 ± 0.032 |
| S      | 0.952 ± 0.020 | 0.952 ± 0.013  |
| $\chi^2$ for 11 central points | 6.9              | 6.8             |

3 parameter fit

| L (mm) | 2.236 ± 0.039 | 2.221 ± 0.032 |
| S      | 0.944 ± 0.023 | 0.945 ± 0.015  |
| D (%)  | 0.9 ± 1.4     | 1.1 ± 1.4     |
| $\chi^2$ for 11 central points | 5.7              | 6.1             |

where by 11 central points we mean 5 bins on each side of the [0, 0.5 mm] central bin.

* 2/3 - $p$ lifetimes consist

Final result

$D = 1.12\% \pm 1.4\% \pm 3.5\% \pm 8.5\%$ [as apply CL]

- 6.3%
Figure 2: Decay length distributions for all the data collected in 1982 and 1983. The line represents the maximum likelihood 3 parameter fit. The log scale plot exhibits a good description of the wings.
Fig. 2. Residual distributions. The points with error bars represent the residual difference (data - model) between the data and the two-parameter curve of the fitted value of $L$ and $S$ with the deviation parameter $D$ set to 0. The lines represent the residual differences with respect to zero deviation expected for various values of the deviation parameter $D$: -3% (dot-dashed line), +1.1% (result of the fit, dashed line), and +5% (dotted line).
...Conclude...

* Theory predicts possible deviations (both QM and Alternative theories)

* We developed a 3-parameter method
  - new physics
  - cross check for $B_g$ and mis-alignments

* We found that $D$ is consistent with zero.
  (no new physics and lifetime consistent with that measured by standard method)