Karlsruhe Institute of Technology

Paritätsverletzung beim β-Zerfall

Versuch Nr. 2

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1 Calibration of energies

At first, the energy discriminator was calibrated. As discussed before, the best results are expected for photon energies higher than 1 MeV. As this is approximately double the rest energy of electrons E_0 and the scattering angle is $\Theta \approx 60°$, the scattered photons have the energy

$$E' = \frac{E}{1 + \frac{E}{E_0}(1 - \cos\Theta)} = \frac{E}{2} = E_0 \approx 0.5\text{MeV}$$

To calibrate the discriminator to this energy, we used ^{22}Na as a β^+ source. When non-relativistic positrons (β^+ particles) and electrons annihilate, two photons with the rest energy of an electron are produced. This process can be seen as a bright line in the spectrum. All other photons generated by the decay of ^{22}Na should have higher energies.

Therefore we tried to set the discriminator so that the first line on the oscilloscope became half as bright as before, cutting all lower events off. This was the case at 151 scale divisions.

2 Measurement

Once the ^{90}Sr+^{90}Y source was placed, count rates for the two orientations were measured alternately. The current for the magnetic coil was always set to 1.4A and the counter was set to 30 seconds. In this way, 31 pairs (N_+, N_-) were recorded. Figure 1 shows N_+ and N_- in chronological order.

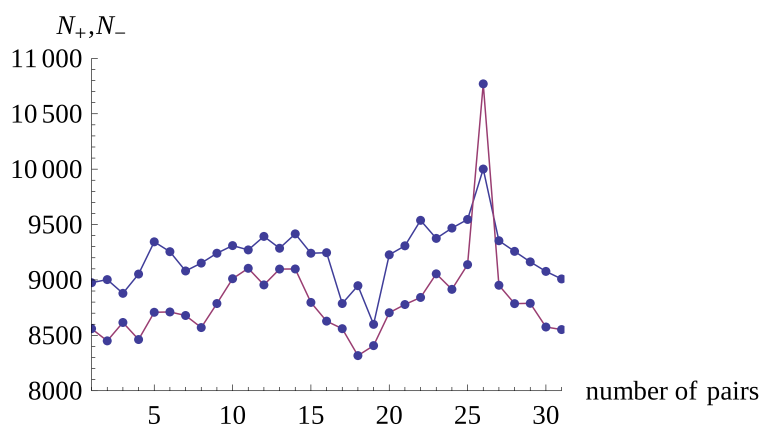

Figure 1: Counts of N_+ and N_- in chronological order

At this point, we can see that the 26th pair is an outlier, which will be marked in all further figures. Presumably there was an external radiation source, perhaps even a cosmic ray event, that only lasted for two consecutive measurements (about one minute).

Because of the radioactive origin, we expected N_+ and N_- to be Poisson distributed. The variance of a Poisson distributed variable equals the expected value. However, the sample variances of N_+ and N_- are notably higher than the sample means (see table 1). In the histograms (Figure 2) one can also see that the Poisson distribution is too narrow to match the distribution of the measured values.

	sample mean	sample variance
N_+ (with outlier)	9219.48	67406.6
N_- (with outlier)	8818.58	181224.
N_+ (without outlier)	9193.43	47968.
N_- (without outlier)	8753.53	51784.

Table 1: Statistical data of counting variables

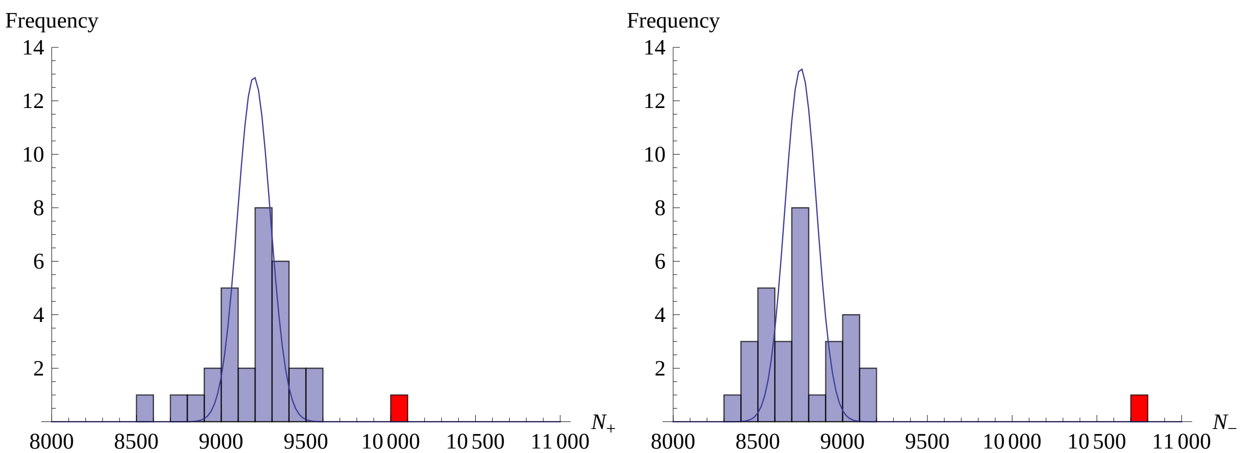

Figure 2: Histograms of N_+ (left) and N_- (right) in comparison with Poisson distributions

The reason for this can already be seen in figure 1. Obviously there is a slow drift in the background radiation or the activity of the source; in addition to the random scattering, both graphs rise and fall in parallel. Therefore consecutive values are not statistically independent and each N has a slightly different distribution.
The scatter plot in figure 3 also shows the corellation between N_+ and N_- , as the points are spread along a diagonal line instead of forming a circular "cloud".
Since the offset doesn't change very much during one pair of measurements, we assume it doesn't affect the difference $N_+ - N_-$ and the relative difference $E = \frac{N_+ - N_+}{N_+ + N_-}$.

3 Outliers

For further calculations, we only regard the relative difference $E = \frac{N_+ - N_+}{N_+ + N_-}$ that is calculated for each pair (N_+, N_-). At first, the sample mean $\overline{E}$ and variance $\sigma_E^2 = \frac{1}{n-1} \sum_{i=1}^{n} (E_i - \overline{E})^2$ was calculated.

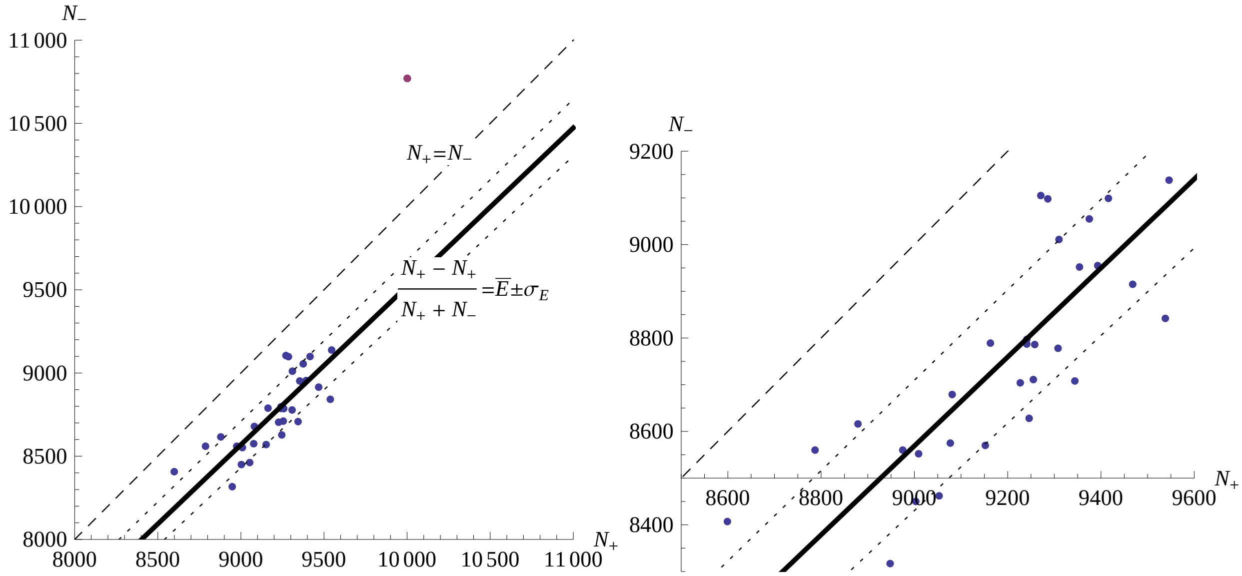

Figure 3: Scatter plots of N_- over N_+ with and without the outlier

According to Chauvenet's criterion, an outlier E^* may be discarded if the expected number of values "worse" than E^* (i.e $|E_i - \overline{E}| \geq |E^* - \overline{E})$ is lower than 0.5, assuming that the values E_i follow a normal distribution with parameters $\overline{E}$ and σ_E^2. Only the previously mentioned 26th data point matches this criterion, having an expected number of 0.0004 worse values.

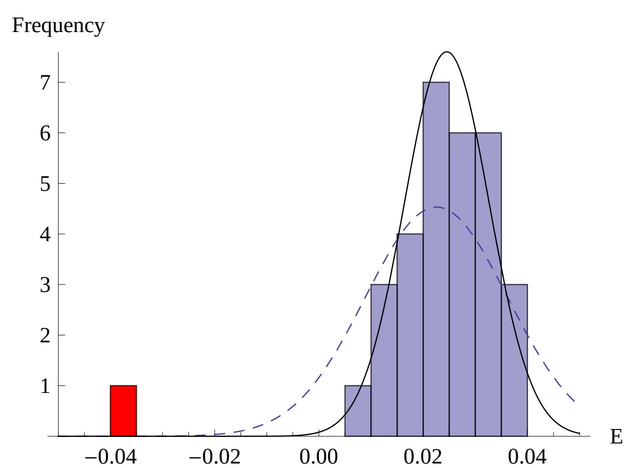

Figure 4: Histogram of E in comparison with normal distributions

Therefore, it was discarded and we get a new mean $\overline{E} = 0.0225$ and standard deviation $\sigma_E = 0.0136$. In figure 4, one can see that the histogram matches the density function of a normal distribution with these parameters, while the original σ_E is too large (dashed graph in figure 4).

4 Background radiation

After the main experiment, we measured the background radiation five times without any radiation sources. The results are listed in table 2. Since we can assume the background to be unpolarized, asymmetries in these values must be caused by systematical errors (e.g. if the photomultiplier is affected by the changing magnetic field).
Although the sample is too small to do a reasonable statistical analysis, there is no evidence that our measurement is influenced by such errors; the mean $|\overline{E}_{\text{back}}|$ is even smaller than its standard deviation.

N_+	N_-	E
281.	275.	0.011
262.	250.	0.023
261.	292.	-0.056
272.	261.	0.021
257.	291.	-0.062

$$\begin{aligned} \overline{E}_{\text{back}} &= -0.013 \\ \sigma_{E_{\text{back}}} &= 0.043 \\ \sigma_{\overline{E}_{\text{back}}} &= 0.019 \end{aligned}$$

Table 2: Background measurement

5 Discussion of errors

When discussing errors, we must keep in mind that we only want to proof that $\overline{E}$ is not zero. Therefore the significance $S = \frac{|\overline{E}|}{\sigma_{\overline{E}}}$ is important, while we aren't really interested in the exact value $\overline{E}$ or even in the degree of polarization. For that reason only the following systematical errors have to be discussed:

- The counter only shows integers and therefore has an error $\sigma_N = 1$
- The background radiation systematically increases $N_+ + N_-$ and decreases E and σ_E. However, this error doesn't need to be corrected because it has no impact on the significance S.

The systematical error of each $E = \frac{N_+ - N_+}{N_+ + N_-}$ is

$$\sigma_{E,\text{sys}} = |E|\sigma_N \sqrt{\left(\frac{2}{N_+ - N_-}\right)^2 + \left(\frac{2}{N_+ + N_-}\right)^2} < 0.00012$$

so our final value[i] is

$$\overline{E} \pm \sigma_{\overline{E},\text{stat}} \pm \sigma_{\overline{E},\text{sys}} = 0.0225 \pm 0.0015 \pm 0.00012$$

Since the significance $S = 15.5$ is very high, it is extremly unlikely that the assymetry is solely caused by errors. We can rest assured that parity is violated.

[i] the inequality $\sigma_{E,\text{sys}} < 0.00012$ holds for all single E, so it also holds for the mean.

6 Polarization of β particles

At the end, we want to estimate the polarization of β particles from the decay. The polarization P_C of the bremsstrahlung[ii] is

$$P_C = \frac{N_- - N_+}{N_- + N_+} \approx \frac{E\Phi_0}{f\Phi_C} \approx 0.563$$

It should be noted that this is an approximate formula and the used values have large errors. The polarization of the original β particles is smaller than that of the Bremsstrahlung because polarization isn't transferred completely.

Quellen

"Blaues Buch"
en.wikipedia.org

[ii] The "blue book" gives the values $\frac{\Phi_C}{\Phi_0} \approx 0.52\pm$ and $f = 2/26$

Appendix:data

Number	N_+	N_-	E	$\sigma_{E,\text{sys}}$
1	8975	8560	0.0237	0.000114
2	9003	8450	0.0317	0.000115
3	8879	8616	0.0150	0.000114
4	9053	8462	0.0337	0.000114
5	9344	8708	0.0352	0.000111
6	9255	8711	0.0303	0.000111
7	9081	8679	0.0226	0.000113
8	9152	8570	0.0328	0.000113
9	9241	8787	0.0252	0.000111
10	9310	9011	0.0163	0.000109
11	9271	9105	0.0090	0.000109
12	9393	8955	0.0239	0.000109
13	9286	9098	0.0102	0.000109
14	9416	9099	0.0171	0.000108
15	9241	8797	0.0246	0.000111
16	9246	8628	0.0346	0.000112
17	8787	8560	0.0131	0.000115
18	8948	8317	0.0365	0.000116
19	8599	8407	0.0113	0.000118
20	9227	8704	0.0292	0.000112
21	9308	8778	0.0293	0.000110
22	9538	8842	0.0379	0.000109
23	9375	9055	0.0173	0.000109
24	9468	8915	0.0301	0.000109
25	9546	9138	0.0218	0.000107
26	10001	10770	-0.0370	0.000096
27	9354	8952	0.0220	0.000109
28	9258	8786	0.0262	0.000111
29	9163	8789	0.0208	0.000111
30	9077	8575	0.0284	0.000113
31	9009	8552	0.0260	0.000114