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New results on the ^{8}Be anomaly

A J Krasznahorkay*, **M Csatlós, L Csige, Z Gácsi, J Gulyás, Á Nagy, N Sas, J Timár, T G Tornyi, I Vajda**
Institute for Nuclear Research, Hungarian Academy of Sciences, MTA Atomki

A Krasznahorkay
CERN, Geneva, Switzerland

E-mail: * kraszna@atomki.hu

Abstract.
Recently, we observed anomalous internal pair creation for the M1 transition depopulating the 18.15 MeV isoscalar 1^{+} state in ^{8}Be. We observed a significant ($\sigma = 7.37$) peak-like deviation from the predicted angular correlation of the e^{+}e pairs at $\theta = 140^{o}$. To the best of our knowledge no nuclear physics related description of such deviation can be made. However, the deviation can be described by assuming the creation and subsequent decay of a boson with mass of ≈17 MeV. In order to clarify the interpretation, we re-investigated the ^{8}Be anomaly with an improved, and independent setup. We have confirmed the signal of the assumed X(17) particle and constrained its mass ($m_0c^2 = 17.01(16)$ MeV) and branching ratio compared to the γ-decay ($B_x = 6(1) \times 10^{-6}$).

1. Introduction

Our current knowledge of Nature at the fundamental level is successfully explained by the Standard Model (SM) of elementary particles, but this theory describes only five percent of the entire content of the Universe. We named the overwhelming unknown constituents as dark matter and dark energy. The nature of dark matter is currently one of the greatest unsolved mysteries in physics.

The search for new physics beyond the SM can be divided into two categories. The first one is the search for new heavy particles and interactions at high energies, the so-called energy frontier research. A complementary and vital role is played by low-energy, precision and/or high-intensity experiments, which require a joint effort of the particle, atomic, and nuclear physics communities [1, 2]. One of the main targets of the intensity frontier in particle physics is a new force carrier which is much lighter than the weak scale and which interacts with the Standard Model particles very weakly. Observations of rare nuclear transitions can be used to search for new hidden force-carrier particles at the MeV scale. In this approach, a fixed target is bombarded with a hadron beam to produce excited states of a nucleus. The excited state then decays also by emitting new particles.

Recently, we have observed an anomaly in the nuclear decay of ^{8}Be [3]. The ^{7}Li(p,γ)^{8}Be reaction was used to populate the excited states in ^{8}Be selectively and the differential internal pair conversion coefficients were studied for the 17.6 MeV, and 18.15 MeV ($J^{\pi} = 1^{+} \rightarrow 0^{+}$) M1 transitions in ^{8}Be. Significant, peak-like enhancement of the internal pair creation was observed at large angles in the angular correlation of the 18.15 MeV transition, but not in the 17.6 MeV one [3]. This observation was interpreted as the creation and the subsequent decay of an X boson with mass m_0c^2=16.70±0.35(stat)±0.5(sys) MeV. The branching ratio of the e^+e^- decay of such a boson to the γ decay of the 18.15 MeV level of ^{8}Be is found to be 5.8×10^{-6} [3].

Zhang and Miller [4] have discussed in detail a possible nuclear physics origin of the anomaly. Therefore, they have improved the existing model of e^+e production in the current experimental context, by including the interferences between E1, E2, and M1 multipoles and by considering two different angular dependencies, and introducing also important constraints from the photon production measurements. These improvements have to be taken into account in extracting new particle properties from such experiments, but can not explain the observed anomaly [4].

J. Feng and his group [5, 6] studied our data along with other previous experiments and showed that our observation strongly disfavors dark photons. Instead, they proposed a new theory and explained the observation by introducing a fifth fundamental force [5]. If confirmed by further experiments, this discovery of a possible fifth force would completely change our understanding of the universe, by taking a step towards the unification of forces and dark matter.

The possible relation of the X boson to the dark matter problem and the fact that it might explain the $(g\text{-}2)_\mu$ puzzle, triggered an enhanced theoretical and experimental interest in the particle and hadron physics community [7]. Inspired by this enhanced interest, we re-measured the effect in different and independent experimental conditions.

2. Experiments

To populate the 18.15 MeV 1^+ state in ^{8}Be selectively, we used the ^{7}Li(p,γ)^{8}Be reaction at the E_p=1030 keV resonance [8]. The average energy loss of protons in the target was 70 keV, so the actual proton energy was 1100 keV. The experiment was performed at the new 2-MV Tandetron accelerator in Debrecen. A proton beam with a typical current of 1.0 μA impinged on 300 μg/cm^2 thick Li target evaporated on 20 $\mu g/cm^2$ thick carbon foil. In contrast to our previous experiment [3, 9], we used a much thinner ^{12}C backing and we increased the number of telescopes (from 5 to 6), which resulted in different electron detection efficiency as a function of the correlation angle. As a considerable improvement, we replaced the gas-filled MWPC detectors with a double-sided silicon strip detector (DSSSD) array.

The e^+e^- pairs were detected by six plastic scintillator + DSSSD detector telescopes placed perpendicularly to the beam direction at azimuthal angles of 0°, 60°, 120°, 180° 240° and 300°. The size of the scintillators is 82×86× 80 mm^3. The positions of the hits were registered by the double-sided silicon strip detectors having strip widths of 3 mm. The telescope detectors were placed around the vacuum chamber made of a carbon fibre tube with a wall thickness of 1 mm.

γ rays were also detected for monitoring purposes. A ϵ_{rel}=100% HPGe detector was used at 25 cm from the target to detect the 18.15 MeV γ rays produced in the ^{7}Li(p,γ)^{8}Be reaction.

3. Efficiency calibration of the e^+e^- spectrometer

The well-known, strong 6.05-MeV IPC transition ($0^+ \rightarrow 0^+$, E0) following the $^{19}\mathrm{F}(\mathrm{p},\alpha)^{16}\mathrm{O}$ reaction was applied to perform the energy calibration of the spectrometer.

The efficiency calibration of the telescopes was made by using the same dataset but with uncorrelated e^+e^- pairs of consecutive events. Accordingly, an energy independent approximation of the efficiency curve could be extracted.

Such an approximation is accurate when only the central sections of the telescopes are in use. This condition was automatically fulfilled in our previous experiments, when MWPC detectors were used with an effective area of 30x30 mm^2.

However, the size of the DSSSD detectors used in the present experiment is 50x50 mm^2 resulting a high probability of event loss when one of the particle escapes from the scintillator.

It results in an efficiency reduction near the surface of the scintillator causing minor deviations in the efficiency curve. Thus, the energy dependence of the efficiency calibration was simulated by the GEANT3 code (for the same e^+e^- sum-energy gate as we used in the experimental data reduction) and taken into account as a correction for the experimentally determined efficiency curve.

The efficiency curve differs considerably for the present and previous setups, as shown in figure 1. Therefore, the present results could be considered as an independent measurement in the sense that any geometry-related systematic effect is eliminated from the measured data.

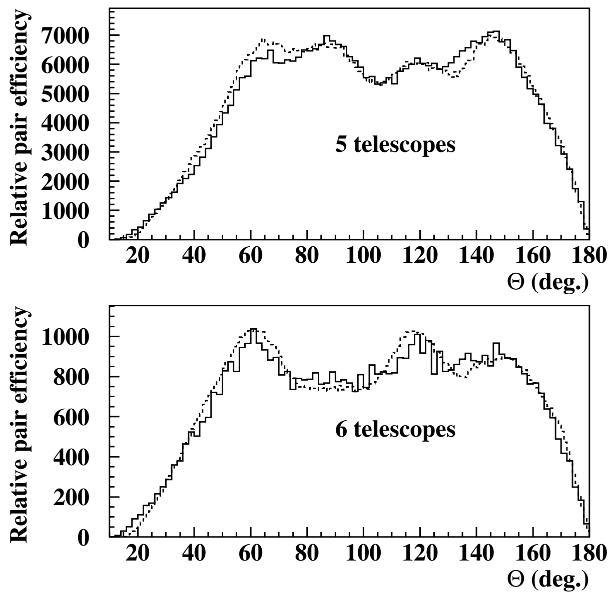

Figure 1. *Measured relative* e^+e^- *pair detection efficiency for the spectrometer with 5 telescopes (upper histogram) and 6 telescopes (lower histogram) compared to the results of the corresponding Monte Carlo simulations (dotted lines).*

4. Subtraction of the background caused by cosmic rays

Since the Q-value of the ^{7}Li(p,γ)^{8}Be reaction is exceptionally large (Q= 17.25 MeV [8]), we were not expecting any background transitions up to 18 MeV. This expectation was also supported by our experimental data obtained for the high energy γ spectra of this energy region, which was completely empty.

However, in an investigation of such rare processes, the cosmic ray background has to be been taken into account. The background was measured for two weeks, before and after the experiment, and was subtracted with an experimentally determined factor from the results by using the same gates and conditions as for the in-beam data. The subtraction factor was derived by setting a high-energy gate (E(sum)=25-50 MeV) on the cosmic rays for both cases (in-beam and off-beam). The cosmic ray background subtraction was then performed until eliminating all events within the high-energy gate.

The shape of the cosmic-ray background angular correlations determined for the 18 MeV gate is shown in figure 2 for the 5 detector and 6 detector configurations.

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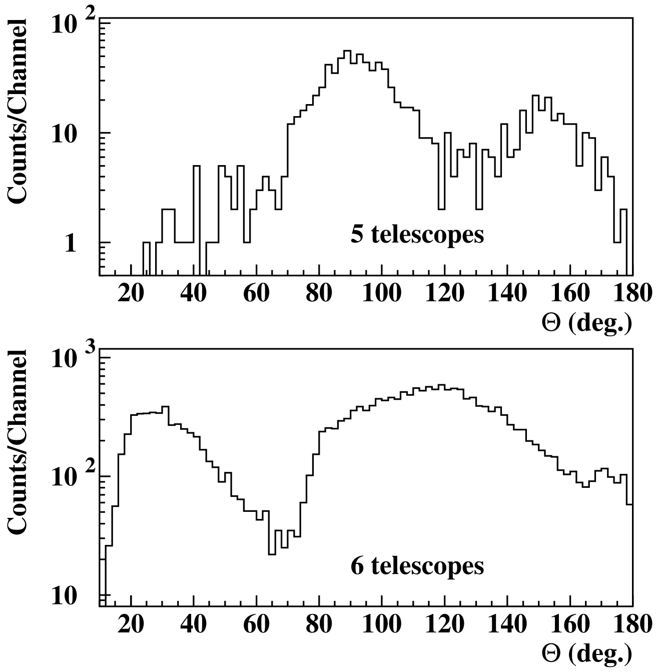

Figure 2. *Relative e^+e^- angular correlations measured for the cosmic rays, analysed in the same way as the 18.15 MeV transition for the spectrometer with 5 telescopes (upper histogram) and 6 telescopes (lower histogram).*

The yield of the cosmic-rays in the present experiment was two times larger compared to the previously published one. The previous experiment was performed in a laboratory situated in the basement of a building with three levels above, while the present one in a lab at ground level, having practically no shielding above.

In order to get a reduction of the cosmic-ray background an active shield were installed above the e^+e^- spectrometer, which was constructed from 12 peaces of 1.0 cm thick, 4.5 cm wide and 100 cm long plastic scintillators. Half of the yield of the cosmic rays could be suppressed this way.

5. Results

Figure 3 shows our experimental results (red dots with error bars) for the recent angular correlation of e^+e^- pairs together with our previous results (blue dots with error bars) [3] measured at the proton absorption resonance at E_p= 1030 keV. There is a very good agreement between the two independent sets of experimental data.

6. Fitting the measured angular correlations

The e^+e^- angular correlation distribution is described as a sum of an exponentially falling background distribution modeled by the IPC simulation, and the signal distribution modeled by the simulation of a boson decaying to e^+e^- pairs.

The fit was performed with RooFit [10] by describing the e^+e^- angular correlation

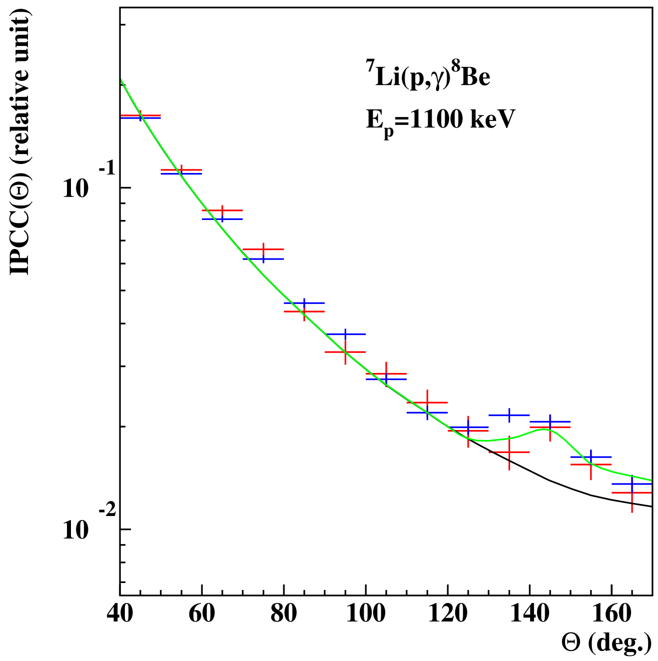

Figure 3. *Measured angular correlations published previously [3] (blue) and the present results (red) of the e^+e^- pairs originated from the decay of the 18.15 MeV ground state transition in ^8Be. The black line represents the background, while the green one is the sum of the signal and background.*

distribution with the following probability density function (PDF):

$$PDF(e^+e^-) = N_{Bkgd} * PDF(IPC) + N_{Sig} * PDF(signal) \ , \quad (1)$$

where N_{Bkgd} and N_{Sig} are the fitted number of background and signal events, respectively.

The signal PDF was constructed as a 2-dimensional model as a function of the e^+e^- opening angle and the mass of the simulated particle. To construct the mass dependence, the PDF linearly interpolates the e^+e^- opening angle distributions simulated for discrete particle masses.

The composite PDF, described in Equation 1, was used to perform a simultaneous fit of N_{Sig} , N_{Bkgd} and the simulated boson's mass. Which were used to calculate the branching ratios for the best fit as well. The results of the two fits are summarized in table 1.

Table 1. Results of the new fit for Exp1 [3] and for the present experiment Exp2.

	Previous res. [3]	Exp1	Exp2	Average
$m_0c^2(MeV)$	16.7(51)	16.86(6)	17.17(7)	17.01(16)
B_x	5.8	$6.8(10) \times 10^{-6}$	$4.7(21) \times 10^{-6}$	$6(1) \times 10^{-6}$
Significance	6.8σ	7.37σ	4.90σ	

The discrepancy in the particle masses of the two data sets could be a result of the unstable beam position in our previous experiment. According to MC simulations, such a mm order of beam position variation can cause a systematic uncertainty that cannot be neglected.

7. Conclusion

We have remeasured the e^+e^- angular correlation for the M1 transition depopulating the 18.15 MeV state in ^{8}Be. We could reproduce the peak-like deviation from the predicted IPC, confirming the signal of the new X(17) particle and constraining its mass ($m_0c^2 = 17.01(16)$ MeV) and branching ratio compared to the γ-decay ($B_x = 6(1) \times 10^{-6}$).

8. Acknowledgements

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