New experimental results for the 17 MeV particle created in ^{8}Be

A.J. Krasznahorkay[1,a], M. Csatlós[1], L. Csige[1], J. Gulyás[1], M. Hunyadi[1], T.J. Ketel[2], A. Krasznahorkay[3], I. Kuti[1], Á. Nagy[1], B.M. Nyakó[1], N. Sas[1], J. Timár[1], and I. Vajda[1]

[1] *Institute for Nuclear Research, Hungarian Academy of Sciences, MTA Atomki*
[2] *Nikhef National Institute for Subatomic Physics, Science Park 105, 1098 XG Amsterdam, The Netherlands*
[3] *CERN,European Organization for Nuclear Reasearch, Geneva, Switzerland*

Abstract. Electron-positron angular correlations were remeasured for the 17.6 MeV ($J^{\pi} = 1^{+} \rightarrow 0^{+}$) ground state transition in ^{8}Be using an improved setup compared to the one we used previously. Significant deviations from the internal pair creation was observed at large angles in the angular correlations, which supports that, in an intermediate step, a neutral isoscalar particle with a mass of 17.0 ±0.2(stat) ±0.5(sys) MeV/c^2 and $J^{\pi} = 1^{+}$ was created.

1 Introduction

Recently, we measured the $e^{+}e^{-}$ angular correlation in internal pair creation for the M1 transition depopulating the 18.15 MeV state in ^{8}Be, and observed a peak-like deviation from the predicted IPC [1]. To the best of our knowledge no nuclear physics related description of such deviation can be made. The deviation between the experimental and theoretical angular correlations is significant and can be described by assuming the creation and subsequent decay of a 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} for the best fit [1].

The data can be explained by a 17 MeV vector gauge boson X that is produced in the decay of the excited state to the ground state, and then decays to $e^{+}e^{-}$ pairs [2]. The X boson would mediate a fifth force with a characteristic range of 12 fm and would have millicharged couplings to up and down quarks and electrons, and a proton coupling that is suppressed relative to neutrons [2]. This protophobic 17 MeV gauge boson can mediate isovector transitions, so there is no dynamical suppression for the decay from the 17.64 MeV 1^{+} state to the ground state. However, its mass is near the 17.64 MeV threshold, thus such a decay is kinematically suppressed. Feng et al., calculated the suppression factor for particle masses of 17 MeV and 17.4 MeV, and obtained values of 2.3 and 5.2, respectively [2]. In spite of that suppression, it would be important to see the anomaly also in the 17.64 MeV transition, since it is a much cleaner case without having any interference effect, therefore we decided to repeat the experiment with better conditions than before [1].

In the present work we also reinvestigated the anomaly observed previously by using a new Tandetron accelerator of our Institute. The multi-wire proportional counters were replaced with silicon

[a]e-mail: kraszna@atomki.hu

DSSD detectors, as well as the complete electronics and data acquisition system was changed from CAMAC to VME.

The expected signature of the new particle is a very characteristic angular correlation of the e^+e^- pairs from its two-particle decay, as shown in Fig.1(a). The predicted angular correlation between the e^+e^- pairs emitted in the internal pair creation (IPC) process [3, 4] however drops rapidly with the correlation angle Θ, as shown in Fig.1(b).

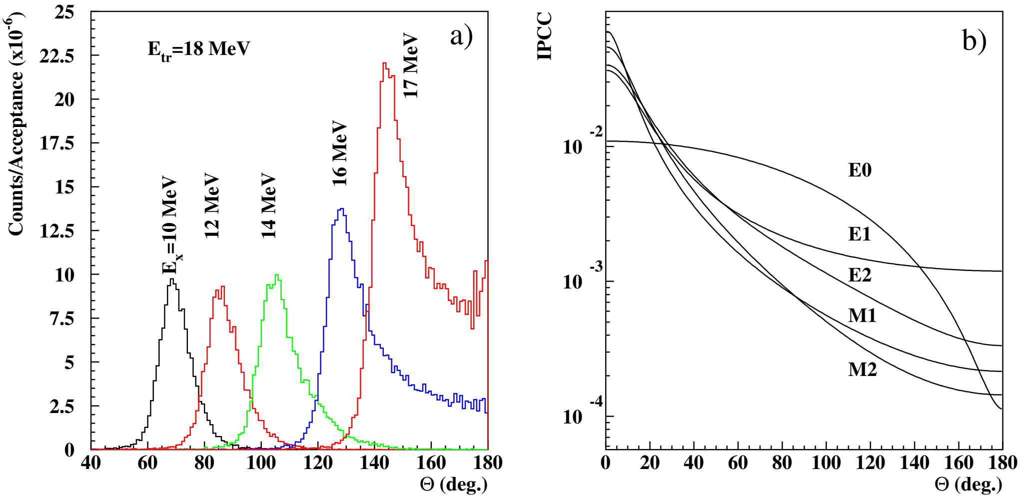

Figure 1. *Simulated angular correlations for boson masses indicated with the different curves (a panel) and for IPC (b panel).*

2 Experiments

To populate the 17.6 MeV 1^+ states in ^{8}Be selectively, we used the ^{7}Li(p,γ)^{8}Be reaction at the E_p=441 keV resonance [5]. The experiments were performed at the 2 MV Tandetron accelerator in Debrecen. A proton beam was used with a typical current of 1.0 μA impinged on a 15 μg/cm^2 thick LiF target evaporated on 10 μm thick Al backing.

The e^+e^- pairs were detected by five plastic ΔE–E detector telescopes placed perpendicularly to the beam direction at azimuthal angles of 0°, 60°, 120°, 180° and 270° around the vacuum chamber made of a carbon fiber tube with a wall thickness of 1 mm [6]. The positions of the hits were registered by double sided silicon strip detectors having strip widths of 3 mm. The target strip foil was perpendicular to the beam direction.

γ rays were also detected for monitoring purposes. An ϵ_{rel}=100% HPGe detector (measured at 1.33 MeV relative to that of a standard 3”-diameter, 3”-long NaI(Tl) scintillator) was used at 25 cm from the target to detect the 17.6 MeV γ rays in the ^{7}Li(p,γ)^{8}Be reaction. A typical γ-ray spectrum measured at E$_p$=441 keV is shown in the left panel of Fig.2.

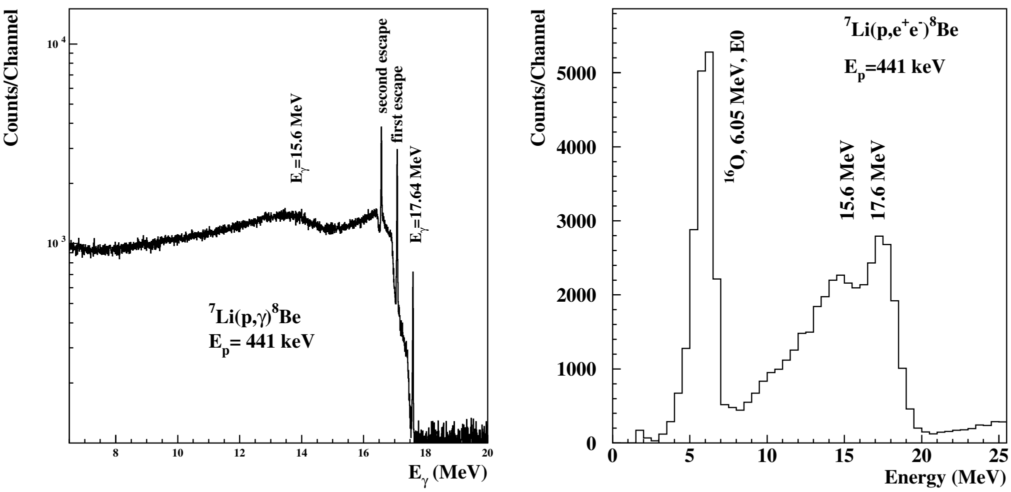

Figure 2. *A typical γ-ray spectrum (left panel) and total energy spectra of e^+e^- pairs (right panel) measured at E_p= 441 keV.*

The 17.6 ($1^+ \rightarrow 0^+$) photopeak and their single and double escape peaks are clearly visible. The broad peaks at 14-15 MeV correspond to transitions to the first excited 2^+ level at E_x = 3.0 MeV, which has a width of Γ = 1.5 MeV [5]. The branching ratios of γ-transition to the ground state and to the 2^+ are about 70% and 30% for the 17.6 MeV 1^+ state, respectively [5].

The exciatation function of the reaction was also measured around the 441 keV resonance in order to check the target thickness. The measured width of the resonance was found to be 15 keV (compared to the real width Γ = 12.2 keV taken from the literature [5]). From this we concluded that the energy loss of the protons in the target was sufficienly small (8.7 keV). In this way we can be sure that the multipolarity of the transition is dominated by M1. The contribution of the direct capture process gives a small background with multipolarity of E1, but according to the excitation function measurements its contribution is less than 1% [7].

The right panel of Fig.2 shows the total energy spectrum of e^+e^- pairs measured at the proton absorption resonance at E_p= 441 keV. The strong 6.05-MeV peak comes from the ^{19}F(p, α)^{16}O reaction followed by the 100% IPC transition ($0^+ \rightarrow 0^+$, E0). This transition was used for energy calibration of the spectrometer and also for checking the efficiency calibration of the telescopes, since the angular correlation of the e^+e^- pairs coming from this transition is well known.

The Monte Carlo simulations of the experiment were performed using the GEANT3 code. Target chamber, target backing, windows, detector geometries were included in order to model the detector response to e^+e^- pairs and γ rays. The scattering of the e^+e^- pairs and the effects of the external pair creation (EPC) in the surrounding materials were also investigated. Besides the IPC process, the background of γ radiation, EPC and multiple lepton scattering were considered in the simulations to facilitate a thorough understanding of the spectrometer and the detector response [6].

The efficiency calibration of the telescopes was performed by using the same dataset but with uncorrelated e^+e^- pairs coming from different events. The energy dependence of the calibration was simulated by the GEANT3 code and taken also into account.

Fig.3 shows our experimental results for the angular correlation of e^+e^- pairs measured at the proton absorption resonance at E_p= 441 keV. In order to check the efficiency of the experimental setup we calculated the angular correlation also for the 6.05 MeV E0 transition coming from ^{16}O. It is shown in the upper curve of Fig.3 a) together with the simulated results for an E0 transition.

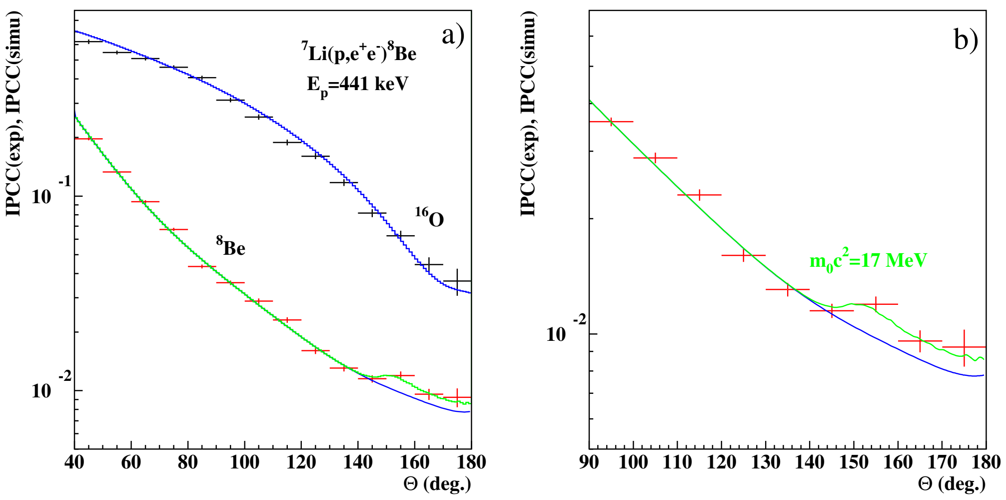

Figure 3. *Measured angular correlation of the e^+e^- pairs originated from the decay of the 17.6 MeV resonance compared with the simulated angular correlations [6] assuming M1+2.0%E1 mixed transitions (full (blue) curve) in panel (b).*

For the 17.6 MeV transition we observed a slight deviation from the simulated pure M1 internal pair conversion correlation (IPCC) curve at large angles. A smoothly increasing difference could be originated from the direct (non-resonant) proton capture, the multipolarity of which dominates E1 [8], and it adds to the M1 decay of the resonance. The contribution of the direct capture depends on the target thickness if the energy loss of the beam in the target is comparable to the width of the resonance. The full simulated curve in Fig. 3b is obtained by adding a small E1 contribution (2.0%) to the dominant M1 one, which describes the experimental data reasonably well, but not a peak-like deviation observed at about 150 degree.

The e^+e^- decay of a hypothetical boson with mass of 17 MeV/c^2 emitted isotropically from the target has been simulated together also with the normal IPC emission of e^+e^- pairs. The results of the angular correlation measurements together with such simulations in a magnified angular range is illustrated in Fig.3b).

DOI: 10.1051/epjconf/201713708010

3 Fitting the Results

The final e^+e^- angle correlation distribution is described by an exponentially falling distribution modeled after the IPC simulation, and the signal distribution modeled from the simulation of a boson decaying to e^+e^- pairs, shown in Figure 4.

The fit was performed with RooFit [9]. Describing the e^+e^- angular correlation distribution with the following probability density function (PDF):

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

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 resulting PDF shape is shown in Figure 4.

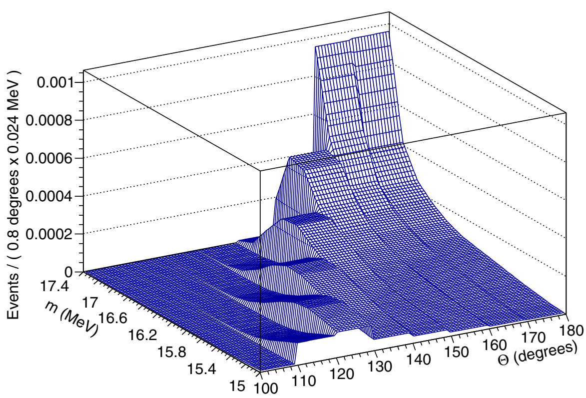

Figure 4. Shape of the PDF describing the hypothetical new particle, as a function of the e^+e^- opening angle and the simulated particle's mass. Normalised to unity.

Using the composite PDF described in Equation 1 we first performed a list of fits, by fixing the simulated particle mass in the signal PDF to a certain value, and letting RooFit estimate the best values for N_{Sig} and N_{Bkgd}. The best fitted values of the likelihood used to minimise the fit is shown in Figure 5c, and has a clear minimum close to 17 MeV/c^2 simulated particle mass. The fitted number of signal and background events as a function of the simulated particle's mass are shown in Figure 5a and 5b respectively.

Letting the particle mass lose in the fit the best fitted mass is calculated as $m = 17.0 \pm 0.2\ MeV/c^2$. The result of this fit is shown in Figure 6. The branching ratio of the e^+e^- decay of such a boson to the γ decay of the 17.64 MeV level of ^{8}Be is found to be 4.0×10^{-6} for the best fit.

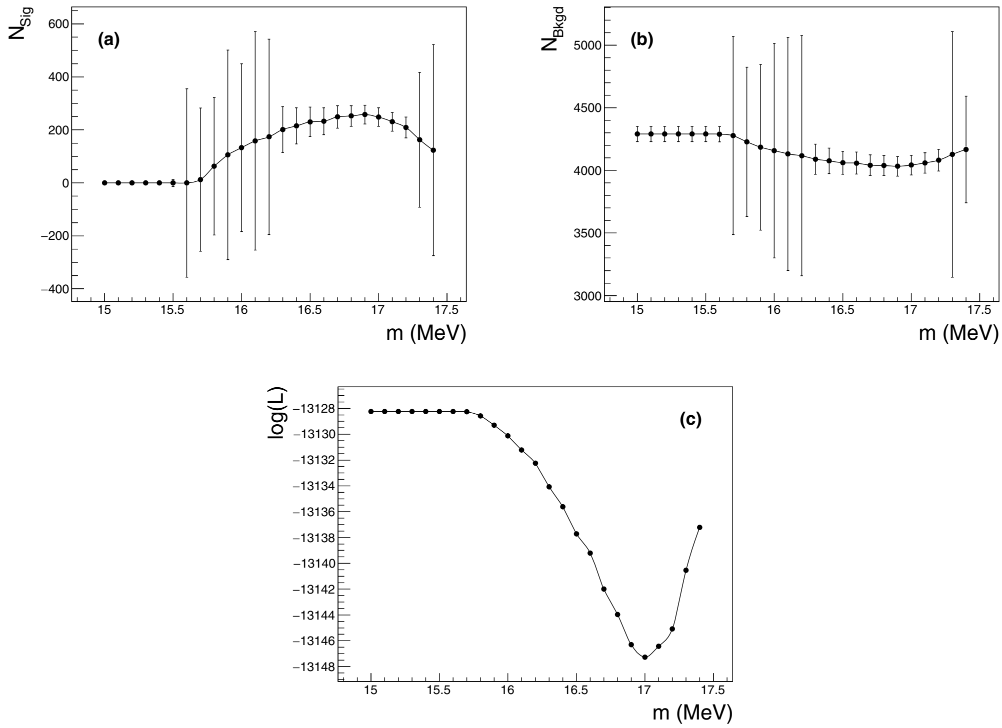

Figure 5. Fit results as a function of the hypothetical new particle's mass.

4 Conclusion

We have measured the e^+e^- angular correlation in internal pair creation for the the M1 transition depopulating the 17.64 MeV state in ^{8}Be, and observed a peak-like deviation from the predicted IPC. To the best of our knowledge, no nuclear physics related description of such deviation can be made. The deviation between the experimental and theoretical angular correlations is significant and can be described by assuming the creation and subsequent decay of a $J^\pi=1^+$ boson with mass m_0c^2=17.0±0.2(stat)±0.5(sys) MeV. The branching ratio of the e^+e^- decay of such a boson to the γ decay (4.0×10^{-6}) agrees nicely with the prediction of Feng et al. [2].

Acknowledgements

The authors are grateful to late Fokke de Boer for suggesting the above studies and motivating us to improve the quality of the experimental data. This work has been supported by the Hungarian OTKA Foundation No. K106035, and by the European Community FP7 - Contract ENSAR n° 262010.

DOI: 10.1051/epjconf/201713708010

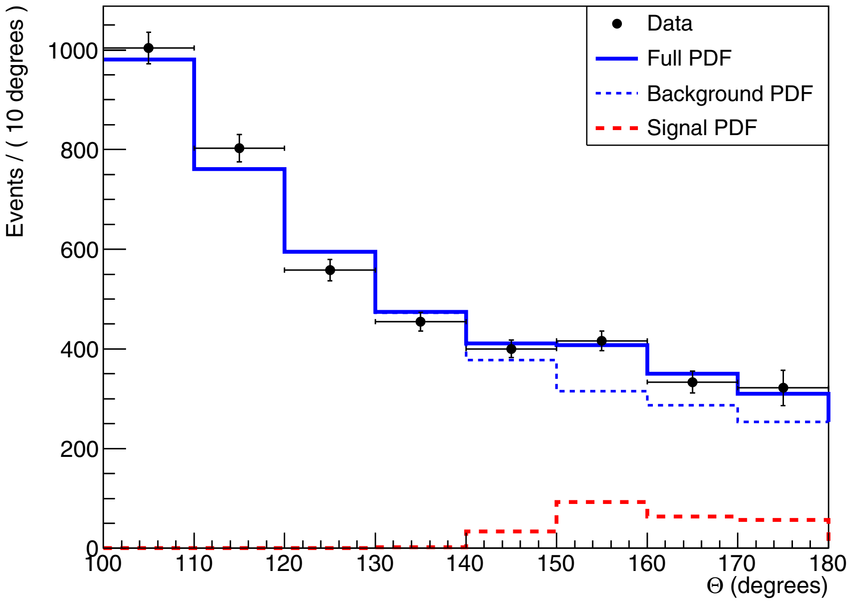

Figure 6. Fit of the e^+e^- correlation angle, letting the fit find the best value of m, N_{Sig} and N_{Bkgd} at the same time.

References

[1] A.J. Krasznahorkay et al., Phys. Rev. Lett. **1**16 042501 (2016)
[2] J. Feng et al., Phys. Rev. Lett. **1**17, 071803 (2016)
[3] M.E. Rose, Phys. Rev. **7**6, 678 (1949)
[4] P. Schlüter, G. Soff, W. Greiner, Phys. Rep. **7**5, 327 (1981)
[5] D.R. Tilley et al., Nucl. Phys. **A**745, 155 (2004)
[6] J. Gulyás et al., Nucl. Instr. and Meth. in Phys. Res. A **8**08, 21 (2016)
[7] D. Zahnow et al., Z. Phys. **A** 351, 229 (1995)
[8] G.A. Fisher et al., Phys. Rev. C **14**, 28 (1976).
[9] W. Verkerke and D. P. Kirkby, "The RooFit toolkit for data modeling," eConf C **0303241** (2003) MOLT007 [physics/0306116].