Graphical imaging system for shifted spectrum in daughter nuclei of charged-current $\nu$-nucleus reactions

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Abstract. In this work, we improve the automated algorithm derived previously for drawing the quantum energy levels, in order to be efficient for plotting the theoretical spectra of the daughter nuclei in charged-current neutrino-nucleus reactions. Such calculated spectra need to be shifted so as the charged-current transition energies to be measured from the ground state of the daughter nucleus. The improvement involves the development of a computational code and graphical imaging system able to treat appropriately and as accurate as possible the energy-shifting which is different for the various multipole sets of nuclear states. The method is applied in the case of antineutrino-nucleus reaction $^{66}_{30}Zn + \bar{\nu}_e \rightarrow e^+ + ^{66}_{29}Cu$, which is of current experimental interest.

1. Introduction

In recent investigations of various physical applications, the development of appropriate computational tools as codes and graphical imaging system requires the simultaneous raw data insertion [5], theoretical calculations or simulated predictions and experimental data insertion [6, 7]. In our previous work, we have developed a graphical imaging system which first determines the appropriate scale to depict graphically as good as possible in the available space the data. This code operates locally and the results are displayed on the screen and can also be exported to a PostScript file. One of its main features is to arrange and visualize in the available space the energy levels of a quantized microscopic system taking care the existence in the final diagram the least auxiliary deviations. This system was applied to the initial nucleus of a charge preserving process. In the present work, we improve the aforementioned algorithm of automated plotting of energy levels in such a way that other requirements like those appeared in charge changing processes (see below) to be satisfied.

1.1. Motivation

The Charged-Current (CC) scattering of low- and intermediate-energy neutrinos and their antimatter counterpart (the anti-neutrinos), on the $^{66}_{30}Zn$ with natural abundance $27.3\%$ isotope are represented by the reactions
\[ \nu_l + ^{66}_{30}Zn \rightarrow l^- + ^{66}_{31}Ga^* , \]  \hspace{1cm} (1)

\[ \bar{\nu}_l + ^{66}_{30}Zn \rightarrow l^+ + ^{66}_{29}Cu^* , \]  \hspace{1cm} (2)

(where \( \ell = e, \mu, \tau \) and \( Ga^*, Cu^* \) denote excited states of Ga and Cu, respectively). Note that, the above reactions of the Zn isotopes play a significant role in the astrophysical environment by affecting the electron fraction of \( Y_e \) of the matter and its strong effect on the matter flow [8].

1.2. The new algorithm

The basic ingredients of the method involve raw data insertion, simulated and experimental data insertion etc [5] (alone or in a combination in methods). The system determines the appropriate scale to show graphically the best possible way within the available space. The main ideas used in the implementation of the developed code are: (i) Public abstract void draw(Shape s) and (ii) Public abstract void draw String(String str, int x,int y) which are described below.

1.2.1. Public abstract void draw(Shape s) Public abstract void draw(Shape s) strokes the outline of a Shape using the settings of the current Graphics2D context.

Parameters: s - the Shape to be rendered. Most of the shapes inserted as a parameter in the draw operation can be defined by using an additional package which is java.awt.geom. In the following example we use java.awt.geom.Line2D which is part of java.awt.geom. In this specific example a line is drawn.

```java
import java.awt.Graphics2D;
import java.awt.geom.Ellipse2D;
import java.awt.geom.Line2D;
import java.io.FileOutputStream;
import java.io.IOException;
import de.erichseifert.vectorgraphics2d.EPSGraphics2D;
EPSGraphics2D g = new EPSGraphics2D(0.0,0.0,210.0,297.0);
g.draw(new Line2D.Double(x, 0.0, x, 297.0));
```

1.2.2. public abstract void draw String(String str, int x,int y) Public abstract void draw String(String str, int x,int y) renders the text of the specified String, using the current text attribute state in the Graphics2D context. The baseline of the first character is at position (x, y) in the User Space.

Parameters:
str - the string to be rendered
x - the x coordinate of the location where the String should be rendered
y - the y coordinate of the location where the String should be rendered

VectorGraphics2D provides the ability to export the graphics in different formats of vector files.

More specifically in formats that are more suitable for incorporating them in research papers such as: (i) Encapsulated PostScript (EPS), (ii) Scalable Vector Graphics (SVG), (iii) Portable Document Format (PDF). Using VectorGraphics2D has some inherited restrictions. More specifically different text encodings are not supported as well as font embedding.

The program’s features are to arrange and visualize, in the available space, the energy levels taking care however, to exist in the final diagram the least auxiliary deviations. Many programs of the existing are very cumbersome due to the complexity of the input data [3], or have not automated this feature and either manually the person concerned puts the deviation he desires in any case [4] either all deviations are only in one direction (usually upwardly). The present
Figure 1. Comparison of the theoretical (right) and experimental spectrum (right) chart of calculated energy spectra in MeV generated in our own automated code for $^{66}_{29}$Cu the daughter nucleus of the reaction $^{66}_{30}$Zn + $\nu$ → $e^+$ + $^{66}_{29}$Cu (left).

The program is user-friendly and the user easily imports the data which are stored to a file. The resulted Figures are very well.
2. Concrete illustrated example
For the calculations of the charged-current (anti)neutrino-nucleus reaction cross sections for various interesting neutrino detectors in terrestrial experiments, one needs to calculate the excitation spectrum of the daughter nucleus. In the QRPA calculations of Ref. [10] for example, starting from the ground state of an even-even nucleus and the system goes to an excited state of the daughter nucleus. As an example, in the case of the COBRA experiment the detector materials adopted are the CdTe and CdZnTe semiconductors. In the present work, which is an extension of Refs [8] and [5], we choose the reaction (2), because the test of our QRPA method is done through checking the reproducibility of the experimental spectra for the daughter nuclear isotopes $^{66}$Ga and $^{66}$Cu one needs to compare theoretical and experimental spectra. The spectrum of the $^{66}$Cu is designed by using the code constructed in this work. Because, however, the energy spectrum of the daughter nucleus must be shifted as discussed in Ref. [9], an improvement of the code is necessary as described below.

In such reactions the obtained theoretical spectrum, usually requires to be shifted so as the lower excitation of each multipole set of states to be well close to the corresponding experimental one. As a concrete example, in the present study we have designed the spectrum of the $^{66}$Cu isotope, daughter nucleus of the charged-current reaction $^{66}$(˜$\nu$, $\ell^+$)$^{66}$Cu*. The code is more advantageous than that of Ref. [9] for example, but a more refinement is needed for a faster and more efficient algorithm which is performing the matching of the shifting procedure optimum.

3. Conclusions
In this work, we have improved the designing code constructed in Ref. [5] in such a way that the spectrum of the daughter nucleus of a charged current reaction of the type $^A_ZX(\nu_\ell, \ell^-)^A_{Z+1}Y^*$ or $^A_ZX(\bar{\nu}_\ell, \ell^+)^A_{Z-1}Y^*$, is perfectly illustrated.

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