



## Virtual Reality Educational Games: a Case Study in Large Scale Particle Physics Research

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### Abstract

Lectures on experimental physics can be complemented by excursions to large-scale research facilities, providing hands-on experience for the students. However, accessibility of the experiment, traveling time and costs might be an issue when visiting a research facility. Therefore we propose to undertake a virtual reality (VR) tour to these facilities, instead. In order to investigate the effort involved in constructing a VR world and the benefit of using VR in education, a VR application prototype has been constructed. As use case we have chosen the Karlsruhe Tritium Neutrino Experiment KATRIN, currently under construction at KIT. In this paper details of the implementation will be presented and its benefit in physics education is discussed.

### 1. Motivation

The learning effect of lectures on experimental particle physics can be enhanced by complementary excursions with student groups to large-scale experiments. Sensual and visual experiences are regarded an essential aspects of learning beyond mere theoretical and experimental lessons. Including additional senses in the learning process supports sustainable comprehension. However, excursions can be expensive and time-consuming. Furthermore, an experimental site might be difficult to reach. During the construction phase some sub-components of the experimental setup might not be on site, or access is not possible at all for safety reasons. Therefore we investigated the possibility of using virtual reality (VR) models as an alternative to on-site visits of large-scale experiments. A VR model can also complement on-site or VR visits by showing parts of the internal setup no longer accessible or by displaying animated simulations of the physics processes involved in the measurement. As a first use case the Karlsruhe Tritium Neutrino Experiment KATRIN (Fig.1), currently under construction at the Karlsruhe Institute of Technology (KIT), has been chosen.

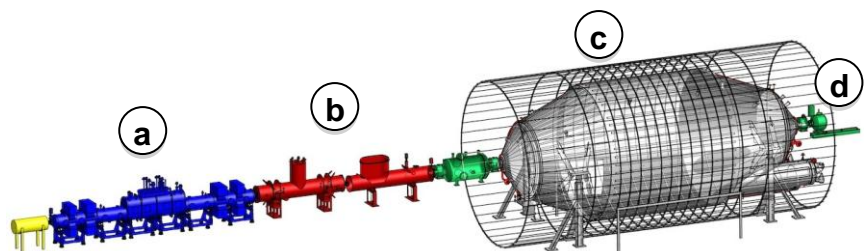


Figure 1: The transport of the main spectrometer to KIT in 2006 and the main experiment components: (a) tritium source (WGTS); (b) transport section (DPS+CPS); (c) main spectrometer; (d) detector.

## 2. The KATRIN experiment

### 2.1 Physics and measurement principle

Neutrinos are the most abundant particles with mass in the universe. Even with a tiny mass they can still have a considerable influence on the development of the universe. Hence, measuring the absolute neutrino mass is not only a major challenge for elementary particle physics, but also for the recently evolved field of astro-particle physics. Observations by other experiments, such as neutrino flavour oscillation measurements, strongly indicate that neutrinos have a finite, but very small mass. However, previous experiments were not sensitive enough to determine the neutrino mass [1,2].

The scientific goal of the KATRIN experiment is the measurement of the mass of neutrinos with a sensitivity of  $0.2 \text{ eV}/c^2$  ( $3.6 \cdot 10^{-37} \text{ kg}$ ), about one million times smaller than the mass of an electron. Since neutrinos are very hard to detect, this is done by precisely measuring the energy of electrons



produced in the radioactive  $\beta$ -decay of gaseous tritium, a heavy hydrogen isotope. The decay produces not only the electron, but also a so-called electron-anti-neutrino. Electron and neutrino share virtually all the energy released in the decay process. Each particle can have an energy between 0 and the maximum energy of 18.6 keV (keV is a commonly used energy unit in particle physics), while the other one gets the remaining energy. KATRIN concentrates on the upper end of the energy spectrum. If the neutrino has mass, the electron spectrum ends below the total energy released in the decay, since a small amount of energy has been used up for the creation of the neutrino mass. With the well-known energy-mass equivalence  $E=mc^2$  from special relativity, KATRIN can measure the neutrino mass, by looking for the missing energy in the electron spectrum.

## 2.2 Experimental setup

The main components of the KATRIN experiment [3] are shown in Fig.1. The 70 m long setup can be subdivided into the *source & transport section* (STS, Fig.1a+b), where the tritium decays take place, and the *spectrometer & detector section* (SDS, Fig.1c+d), where the energies of the decay electrons are measured. Decay electrons from the tritium source are guided magnetically to the large electrostatic main spectrometer with a diameter of 10 m. The remaining tritium gas is pumped out at both ends of the source and recirculated in a closed loop. Electrons, which reach the spectrometer, are slowed down by the electric field. Electrons with lower energies are repelled, while those with higher energies pass the spectrometer, hitting a detector, where they are counted by the data acquisition system. The shape of the electron spectrum can be scanned by varying the retarding voltage of the spectrometer and comparing the count rates of the detector.

The high precision needed for this measurement requires a very stable flow of the tritium gas in the source, highly stable and accurate high voltage and ultra-high vacuum conditions at all times in the spectrometer section. The relevant processes in KATRIN are invisible to human senses. The sensitive operating conditions allow only very limited access to the experiment for visitors. With thousands of visitors each year, KATRIN is an ideal use case to enhance the user experience by a VR application.

## 3. Basic design of the virtual world application

The educational game should meet high requirements comparable to real computer games. However we didn't want to compete with commercial or professional games. This led us to demand the following specifications.

- **Educational requirements:** The application shall illustrate the dimensions of the real setup. All buildings and components should be explorable (see Fig.1). An on-site visitor should be able to recognize all buildings and components from the VR world and vice versa.
- **Technical requirements:** Developing the application should not be too expensive. Affordable or open source software should be used, where possible. Available technical and architectural design drawings should be used for most time consuming tasks to construct the geometry of the VR world.

The presented version of the VR application is not intended to show detailed simulations of the physical processes or explain the physics in detail. This task is left to a teacher or guide. However, a visitor should get a basic idea of the technical interplay of the main components and therefore should be able to find appropriate information inside the VR application.

## 4. Building the VR KATRIN world

The VR model is based on the original CAD technical drawings of the experiment. Thus the virtual experiment setup matches reality with respect to shape and size. The main construction tool was the open source software Blender™[4,5](Fig.2). For necessary simplifications of CAD drawing, Inventor 2014™ and 3ds Max™ from Autodesk™[6] and the open source tool MeshLab™ [7] were used. The navigation has been implemented according to the WASD control scheme [8], which is common to many adventure games and provides the advantage, that many young people are already familiar with this interface.

As 3D-display a LG 47LM615S (119 cm/47") TV-set for stereoscopic presentations is used, which is appropriate for small visitor groups. The VR application does not require dedicated PC hardware and thus can be used for individual exploration of the virtual experiment, e.g. by students at their own notebook. However, a mid-range graphics card is recommended.

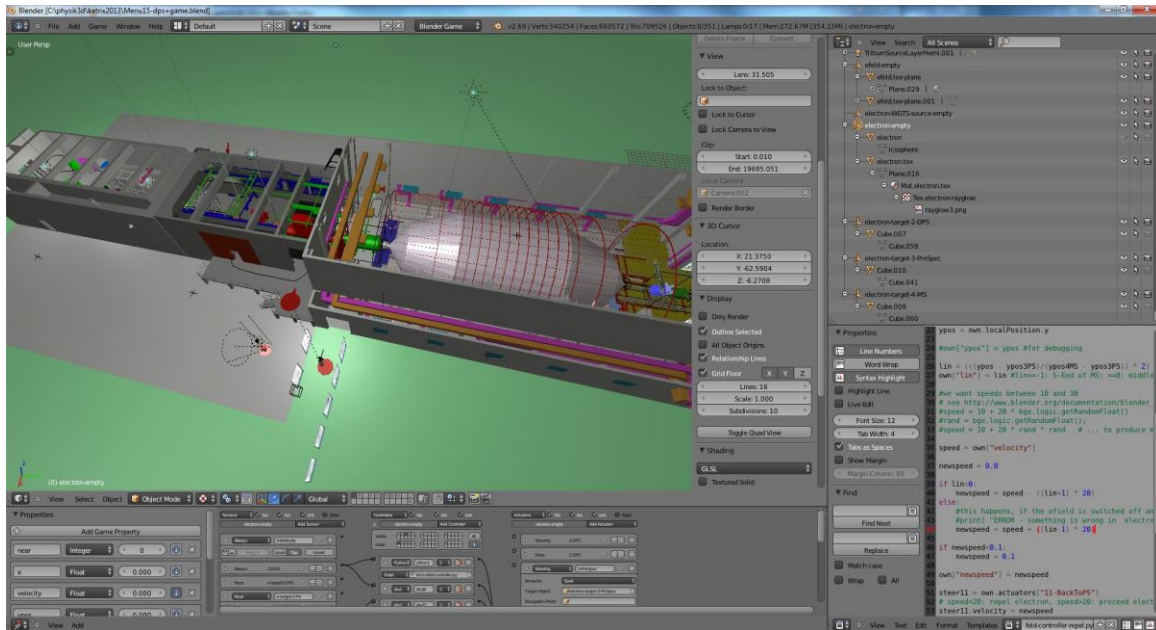


Figure 2: The virtual experiment in the Blender development environment; the top left part shows the Blender 3D view; bottom: game logic editor; right: outliner and Python script editor

## 5. Using the VR application

The VR world can be explored in two different modes: In the first mode the user can roam freely in the experimental halls or follow a virtual tour to become familiar with the experiment. A guide can use this mode to visit the important locations. This mode is recommended when using a large stereoscopic screen for visitor groups. The second mode is the game mode, which requires visiting four locations of the experiment and solving a task as fast as possible.

### 5.1 Virtual tour

The VR application can be used to walk freely through all experimental halls and to inspect the components of the KATRIN experiment. Adjacent to each component a virtual 'info point' describes its functionality. Most of the 'info points' are virtual posters, similar to those displayed in the real experimental halls. A virtual round trip is marked by red arrows and guides the visitor on a tour to all interesting locations (Fig.3a). User instructions for the application are placed at the starting point of the VR world (Fig.3b). The user can start an animation of an electron path inside the experiment. Pressing the key X activates the x-ray mode, which allows to view the interior of some of the components and to watch the electron beam (Fig.3c,d and Fig.4c).

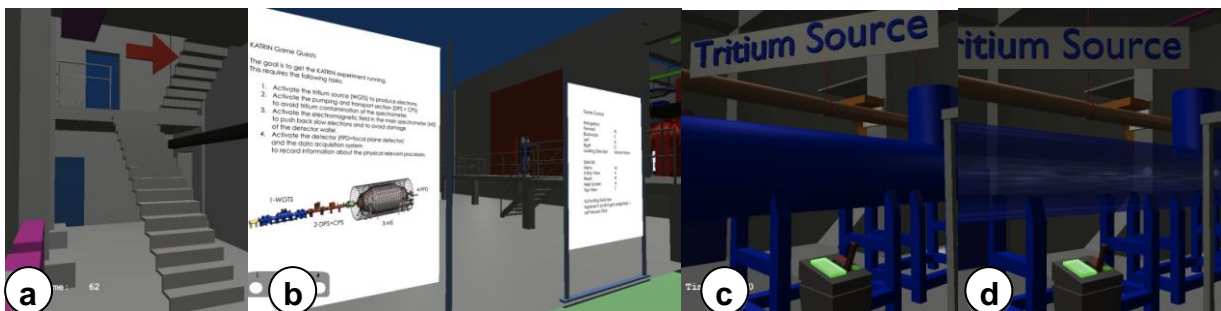


Figure 3: (a) Round trip marked with arrows; (b) virtual posters for usage and gameplay instructions; (c) tritium source vessel, standard view and (d) x-ray view, revealing the tritium flow and electrons



A bird's eye mode, showing the buildings and the current user location from above, helps reorienting oneself. After concluding their virtual round trip, visitors can test their understanding of the experiment with a little game.

## 5.2 The game: Enter the KATRIX

In order to become familiar with experimental modes of operation a little game has been integrated into the VR application. In order to conclude the game, it is necessary to have visited the 'info points' of the virtual round trip and to understand the basic principles of the experimental setup. The objective of the game is to activate all main components and use the detector for counting electrons and measuring their energies. In the current version the player needs to find switches (Fig.4d) in the vicinity of the respective components and activate them. A head-up display (HUD) shows the progress and the elapsed time (Fig. 4e). The game introduces a playful interaction with the experiment, which would never be possible in an on-site visit.

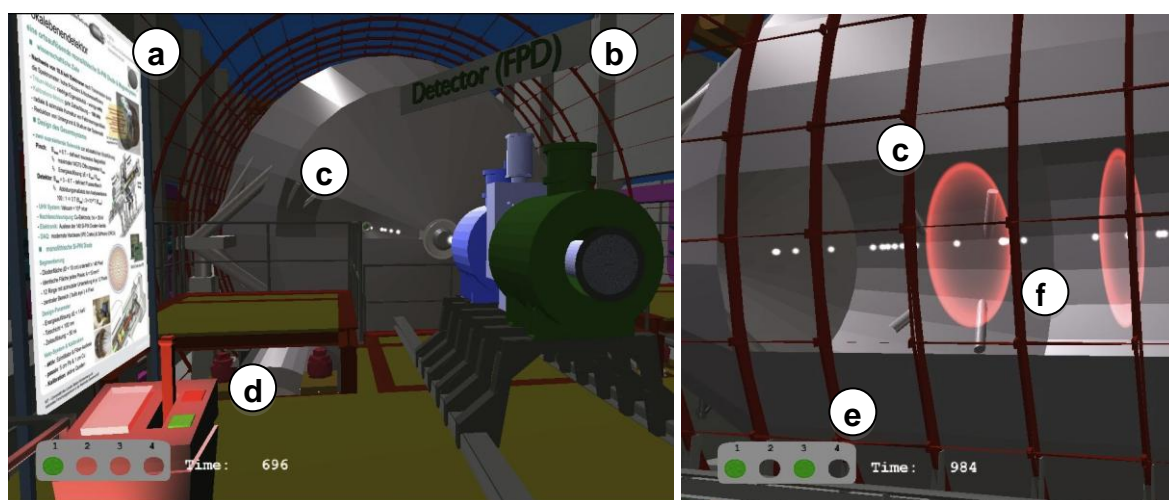


Figure 4: Virtual experiment details: (a) info poster; (b) plate with component name; (c) transparent surface or window in x-ray view mode; (d) game puzzle switch; (e) HUD with game point counter and timer; (f) animation of physical processes inside the experiment facilities

## 6. Discussion and conclusion

The educational VR game for the KATRIN experiment has been created with reasonable effort compared to commercial games. The development required roughly 1 man-year. With the established workflows the task could be repeated for another setup in approximately half of the time, providing that the respective CAD drawings are available.

VR systems provide a viable alternative to on-site visits of large-scale research facilities. Users of the VR application can get a close-to-reality impression of the experimental setup with respect to shape and size. They can acquire information about the experiment by navigating through the VR world and reading the virtual posters. Animations visualize otherwise invisible processes, enhancing the understanding of the experiment and the physics involved. Since animations are only a simplified illustration of complex processes, it might also be helpful to have a teacher or guide at hand, who can explain the details and shortcomings of the animations. In addition the integrated game allows some interaction with the experimental setup, providing a playful access to particle physics. This is a welcome feature especially for experiments where functional parts are completely hidden from the eye of the visitor.

## 7. Outlook

### 7.1 Evaluation

Recently we started a poll among users of the educational game, in order to evaluate, whether we achieved our goals or not. A preliminary analysis of the still limited number of returned questionnaires indicate that users enjoy playing the game. It has a high 'fun factor' and often it raises the interest in learning more about the experiment. In addition users are able to associate components in the artificial virtual world with their counterparts in the real world, which justifies our simplifications in the game



design. Simplifications (e.g. no textures, coloured components, missing details) do not disturb the spatial sensation with respect to shape and size, which was one of the main goals.

## 7.2 Scientific and process visualization

There are two obvious extensions of the VR application planned. The first update should visualize the results of simulations of physical processes like the path of an electron. One could imagine taking a rollercoaster ride on an electron from creation to detection. The second enhancement would be the visualization of the state of the real experiment, using measured sensor data, such as temperature, pressure, electric potential or magnetic fields. These extensions might have the potential to change our way to analyse data or operate an experiment.

## Acknowledgement

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