Summer Student project: ALPHAVR

Introduction

The ALPHA experiment aims to understand the world of anti-matter. It does this by combining anti-protons and positrons together to form anti-hydrogen. This is then trapped until it eventually annihilates, at which point information about the anti-hydrogen and the collision can be collected and analyzed.

The task of my summer project was to replicate the ALPHA Experiment using VR for educational purposes, given the name ALPHAVR. A user of this application can move around the experiment, look at the machines close up and even interact with them. Furthermore one can go inside some of the machines to take a closer look of what really happens at a smaller scale.

Tools Used

The main tool used for this project is Unity, which is a game development engine. This engine has many in-built features that facilitate game mechanics for developers, such as creating and placing objects, while also giving access to debugging and performance analysis tools, which help optimize the game. Unity also allows the user to create simple animation and particle systems that can be used for in-game events like collisions and explosions. The reason Unity was chosen as a game engine is because it is user friendly and well documented online.

While Unity game engine focuses on the aesthetics and scene design of the simulation, the actual game logic is implemented programmatically using C#. This is used in practically every aspect of the simulation to implement the logic of what the player can do and what happens to the surroundings once certain events occur. For example the movement of the player, interaction with the machines and the movement of the animated particles are all handled in C#.

The ready-made CAD models of the experiment were obtained from Inventor2017, however importing these models directly in Unity results in massive performance costs due to their complex nature and fine detail. For this reason another tool was needed to simplify the models' mesh in order to optimize the game. Blender, a free modelling tool, was used to combine the many small details like nuts and bolts into one big object, which is much more manageable for the CPU. Another important use of Blender was to simplify the geometry of the models by reducing the number of polygons that make up an object. For example if the original number of polygons of a flat square face contained 10 polygons, Blender manages to reduce this number to about 1 or 2 as it recognizes the required number of polygons needed for a flat square surface which will roughly result in the same object as the original.

Finally, an HTC Vive Pro was used as a VR headset, which allows you to look around, along with two controllers, which allow you to move around, change scenes and interact with objects.

Project Explanation

The simulation takes place in the AD factory at CERN. The player spawns in front of the experiment, seeing the main machines that are used by the experiment to create anti-hydrogen (fig. 1). These machines are:

- ELENA: which feeds an anti-proton to the catching Trap
- Catching Trap: traps anti-protons, which will eventually be sent to the Atom Trap
- Accumulator: where a radioactive beta-decay source (Na-22) emits positrons, which are also sent to the Atom Trap after being captured and containing the desired number and size
- Atom Trap: which traps and holds antihydrogen atoms until annihilation
- ALPHAg: which is an upgraded version of the Atom Trap. This is only visible in the game after a button is pressed

Figure 1: Full Setup

From this point you can teleport around by pointing the controllers, pressing the button to point a laser to the desired location and finally releasing the button to teleport. This allows you to move closer to the machines and look at them in detail, even allowing you to look inside the machines to see how the inside works and what the components look like.

Another feature implemented in the simulation is that you can point the laser towards the machines, and once released the machines are sliced in half so that you can see the cross-section of the chambers (fig. 2).

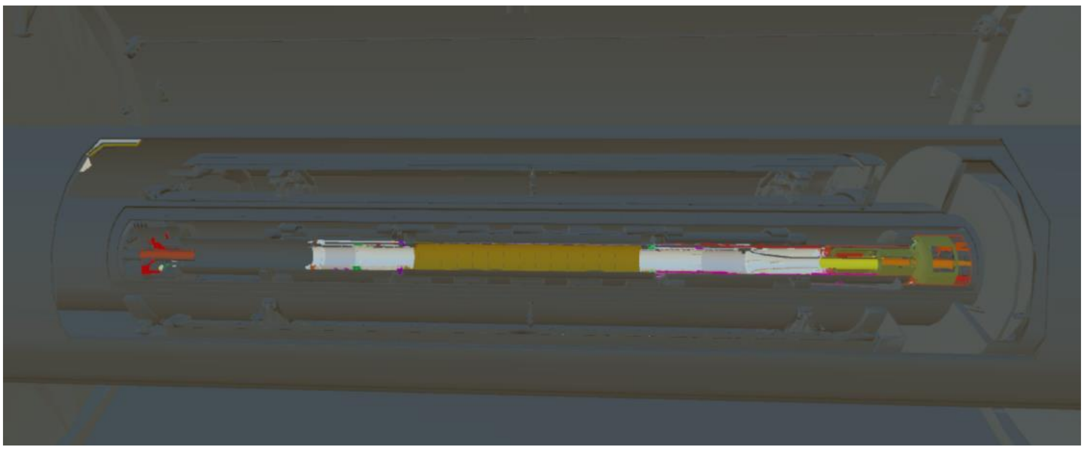
Figure 2: Sliced Atom Trap

There are three buttons around the experiment that one can interact with. Two of them are in front of the catching trap and the atom trap. Once the buttons are physically pressed by the controller, the aforementioned machines are then moved forward/backwards on a slider. When the third button is pressed, the accumulator starts sliding to the right until it stops. At this point, the new upgraded machines, ALPHAg along with a beamline and its frame, slide into place to show how the new setup looks like.

After exploring around, one can even see how the individual machines work by 'shrinking' inside them. This is done by pointing the laser at a machine and pressing another button on the controller. After a few seconds of them being pressed the scene changes and you are spawned inside the machine. Given below is a brief description of what happens once inside each of these machines.

For the catching trap, anti-protons start moving inside the tube and through a foil. A few of the anti-protons annihilate with this foil, giving out a particle animation to indicate this. Once the rest of them manage to pass through this foil, they will reach a point at which some are 'reflected' back and others are lost and keep on going through due to their high energy. The rest of the remaining particles are trapped in this tube and oscillate backwards and forwards. All of these surviving particles will eventually slow down and are trapped in the middle. In the meantime the player has the ability to move around the tube and examine everything at a closer position.

Once the Atom Trap scene is loaded, you are spawned in the middle of the tube and are able to look around without moving from your original position. At both ends of the tube, two particles can be seen moving in opposite directions, an anti-proton and a positron (fig. 3). Once these collide write in front of the player, they slow down, and anti-hydrogen is created within a span of a second. These particles then oscillate across the tube, following paths obtained from actual data. Some of these particles collide and annihilate with the sides of the tube, creating an explosion animation as well as releasing 4 paths from the point of collision, representing the newly created pions. The pions collide with three layers of detectors, and the paths of these pions are inferred from this information. After a while, the number of collisions decrease, and what remains is a couple of trapped antihydrogen in the middle.

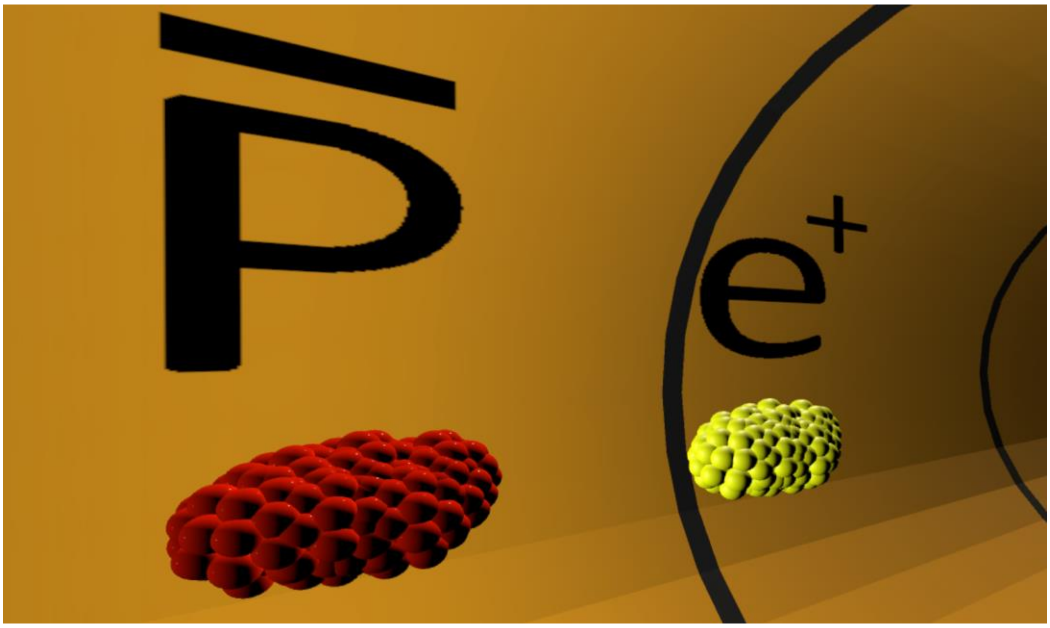

Figure 3: Atom Trap

The ALPHAg scene is similar to the Atom trap, with the difference that it is flipped vertically rather than horizontally. Also the trapped particles in the end, similarly as mentioned for the atom trap, start oscillating vertically in a much more obvious manner than in the atom trap to indicate that they are trapped. After a couple of seconds, these remaining anti-hydrogen atoms have a 50:50 chance of going up or down the tube, and will eventually annihilate. Information about these annihilations are then gathered and analyzed to better understand the nature of these particles.

Improvements

The scene designs can be significantly improved by adding more detailed textures and materials to the models of the machines and the surrounding room since they were left in the original format of the CAD models. Lighting is a big aspect that would improve the immersion of the simulation, however not much lighting was implemented. The reason for this is that since the machines have complex surfaces, even a simple lighting system would require heavy computation to display the appropriate shadows and lighting effects. Collision and explosion animations could be recreated using different tools that are specifically intended for these purposes, allowing for a higher attention to detail.

Other interesting scenes that could be added is one for the accumulator, where a representation of the radioactive source emitting positrons can be shown, some of which manage to go through to the atom trap. The catching trap could also see significant improvements in both its design and its animations. The anti-protons were given a simple ellipsoid mesh rather than a more complex one as in the atom trap. The reason for this is that multiple antiprotons with a complicated mesh would significantly slow down the performance of the simulation. Moreover the movements of the anti-protons currently follow a horizontal straight line, which is not realistic.

The physics simulations inside the machines are not completely accurate and to scale in order to simplify computation, however adjustments to make the physics more realistic would be beneficial. Apart from this, there could be some form of explanation while the experiments run, maybe in text form or audio form. This would make it much easier for the user to understand what s/he is seeing.

The simulation can be optimized by further reducing the number of polygons on certain objects, as well as using simpler machines. Controls could also be chosen in such a way that they are more intuitive.