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Crowdsourcing CP Violation

Cambridge Perse Team (CPT)

Motivation

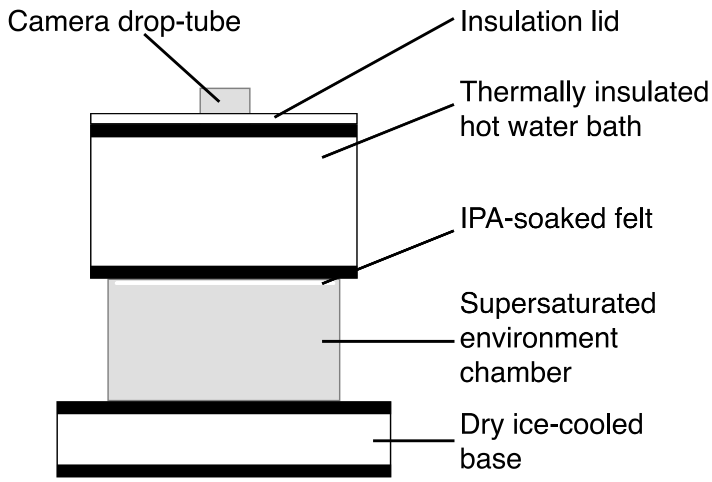
We are a team of aspiring physicists from The Perse School, Cambridge. Our aim is to honour the ingenuity of previous generations of particle physicists whilst simultaneously inspiring a new generation in schools today. The opportunity to be able to share our work with many people and get them excited about particle physics and STEM subjects is one which we would relish. We have designed, built and tested a cloud chamber that can be constructed from materials available in most schools. We propose using our cloud chamber to recreate a number of the most fundamental and revolutionary historical experiments at CERN. We intend to share the images we record online and crowdsource their analysis, allowing physics students from around the world to join our experiment.

Project proposal

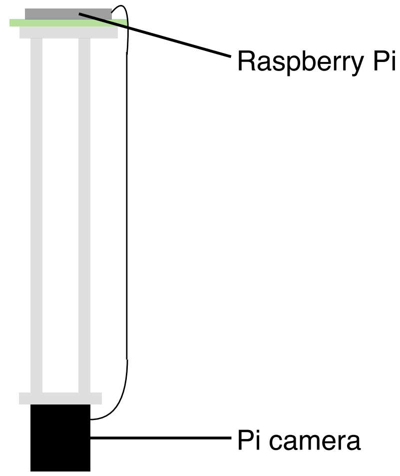
Cloud chamber

We have engineered a prototype which only requires a source of dry ice and hot water to function. Our prototype is constructed from acrylic plastic and PVC. Integrated into the apparatus we have a Raspberry Pi camera, which has 5-megapixel resolution at 15 fps. The cloud chamber and Raspberry Pi camera mount. is illustrated in Figure 1. We have successfully tested the cloud chamber with a ^{241}Am α-particle source; a still image from this test is shown in Figure 2.

We have also devised a method for videoing the trails in 3D by filming the particle event from multiple angles using two cameras. This has not been incorporated into the prototype, but later iterations of the design could include this functionality. Furthermore, we are also considering adjusting our design to use a salt-ice bath, which is more readily available, instead of dry ice.



(a) Side view diagram of the prototype cloud chamber.



(b) Side view diagram of Raspberry Pi camera mount

Figure 1: Diagrams illustrating the prototype cloud chamber. The Raspberry Pi camera mount slots into the camera drop-tube and can view the full chamber below.

Figure 2: Image taken by Raspberry Pi camera during testing with α-particle source.

Crowdsourced analysis

We would run our cloud chamber in the CERN beamline, and use the Raspberry Pi to collect images of the particle events in the chamber. We will then put our images online and crowdsource their analysis. We will invite Physics students from across the world to take part in our experiment, potentially engaging with particle physics for the first time: they would be given full responsibility for their analysis and would be making an original contribution to the field whilst learning. This allows a large amount of data to be analysed in a short timeframe.

We have created a website using the Zooniverse[1] platform for sharing, analysing and disseminating our research. If we progress, this will include tutorial videos that show the students how to identify certain particles from the tracks and how to use the website tools. The students can then work through the cloud chamber images taken at CERN, drawing tracks over the particle images and deducing what particles were present in each collision and decay. We will also include links to other websites and news on this topic and the basics of particle physics.

Cloud chamber images provide a good way to teach students particle physics: since they are effectively photographs of particle decays taking place, they can give a strong visual understanding of the behavior of subatomic particles.

Since a Raspberry Pi is fundamental to our design, the Raspberry Pi Foundation have agreed that if we are successful in this competition they will include an article about our project on their website. Furthermore, Founders4Schools have agreed to include a section on us in their weekly newsletter to teachers around the UK. In addition, we would promote our project through social media and by contacting secondary schools.

CP violation and the Fitch-Cronin experiment

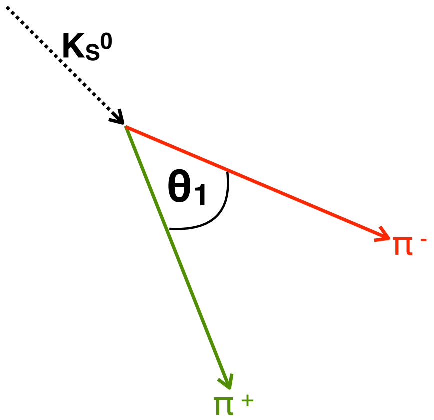
Our main aim at CERN would be to conduct an experiment to observe CP violation, since it is one of the major unknowns in particle physics. We would aim to recreate the Fitch-Cronin Experiment of 1963, where a beam of K-mesons was observed.[4] The beam would consist of two types of kaons: the K_S^0 and the K_L^0 which both have different mean lifetimes[5]:

$$K_L^0 \quad : \quad (5.116 \pm 0.021) \times 10^{-8} \text{ s}$$
$$K_S^0 \quad : \quad (8.954 \pm 0.004) \times 10^{-11} \text{ s}$$

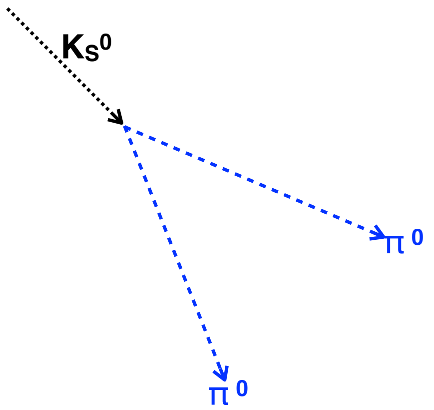
At velocities close to the speed of light, this can be translated into average distances before decaying:

$$K_L^0 \quad : \quad (15.34 \pm 0.06) \text{ m}$$
$$K_S^0 \quad : \quad (0.0268 \pm 0.0001) \text{ m}$$

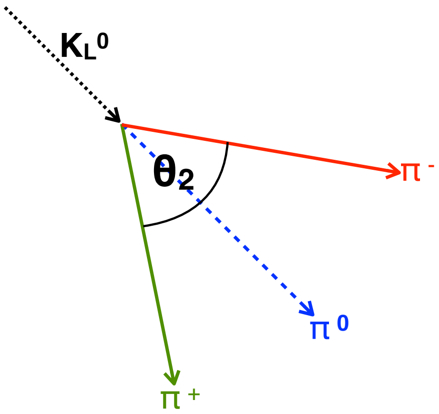
This huge difference in decay distances between the K_L^0 and K_S^0 should allow us to assume that after 10 to 12 m of neutral kaon beam, there should theoretically and statistically be only undecayed K_L^0 particles left.



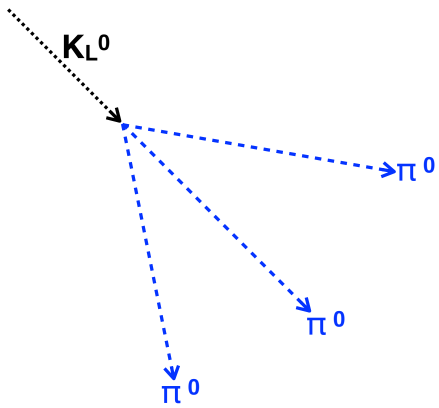
(a) Decay of K_S^0 to charged pions



(b) Decay of K_S^0 to neutral pions



(c) Decay of K_L^0 to charged and neutral pions



(d) Decay of K_L^0 to neutral pions

Figure 3: Decay patterns of K_L^0 and K_S^0 mesons. Dotted lines signify undetectable neutral particles and solid lines represent detectable charged particles.

The decay processes of K_L^0 and K_S^0 particles are shown in Figure 3. Theoretically, the beam should consist only of K_L^0 particles, which decay into three pions. If the K_L^0 particles decays into two charged pions and one neutral pion as in Figure 3(c), we can distinguish this from the K_S^0 decay in Figure 3(a) by measuring the angle between the tracks formed: $\theta_1 < \theta_2$.

By the time the beam reaches the chamber there should theoretically be no more K_S^0 particles, because they would have all decayed into pions. If there are K_S^0 particle decays in the cloud chamber, this suggests that a K-long particle instantly switched from a K_L^0 to a K_S^0; this breaches conservation of charge and parity[6] and demonstrates CP violation.

Beamline setup

For the main CP violation experiment we would empty the 2 Cherenkovs and utilise an absorber to filter out all particles except neutral kaons. Our beamline setup is illustrated in Figure 4.

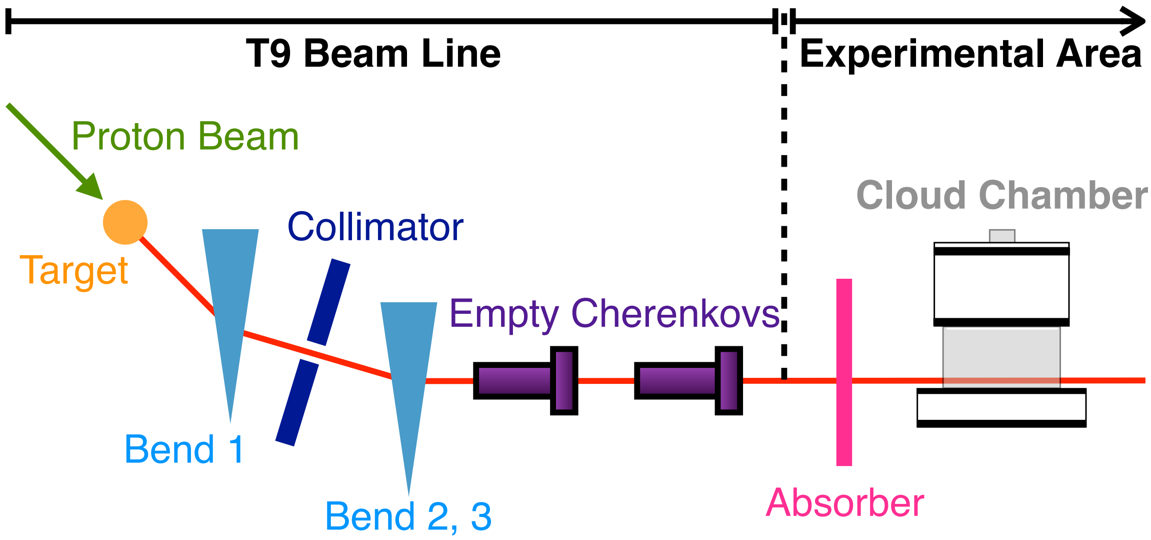


Figure 4: Schematic of the beamline setup used to run the CP violation experiment.

After running the experiment and collecting images of particle tracks in our detector, we would put the images onto our Zooniverse platform, and ask students and others to analyse our images to determine if any of the K_L^0 particles switched to K_S^0 particles.

If we have more time at CERN, we would seek to replicate some other ground-breaking particle physics experiments in order to have a broader range of images for analysis. For example, we would try to recreate Carl Anderson's 1936 experiment which led to the first observation of an antimatter particle, the positron.[7] This experiment was originally conducted using a cloud chamber, and the discovery of antimatter played a huge role in particle physics in subsequent years.

Conclusion

To conclude, our aim in this project is twofold: to honor the legacy of the great pioneers of particle physics and experimental physics and to inspire a new generation of students to get involved with these fields today. We hope that by crowdsourcing the analysis of our images to students around the world, we can give students a better understanding of this fascinating area of physics. By seeking to observe CP violation using a simple school-laboratory apparatus, we would also demonstrate that the frontiers of particle physics are not as inaccessible to school students as they might seem.

References

[1]Link to our Zooniverse page: https://www.zooniverse.org/projects/pratapsingh1729/team-cpt-beamline-4-schools

[2]Link to Raspberry Pi homepage: https://www.raspberrypi.org/

[3]Link to Founders4Schools homepage: https://www.founders4schools.org.uk/#/

[4]J. H. Christenson, J. W. Cronin, V. L. Fitch, and R. Turlay. *Evidence for the* 2π *decay of the* K_2^0 *meson.* Phys. Rev. Lett., **13** 4 138 (1964)

[5]K.A. Olive *et al.* (Particle Data Group), Chin. Phys. C, **38** 090001 (2014) and 2015 update.

[6]Prof. Mark Thomson. *The CKM Matrix and CP Violation.* Handout 12 from University of Cambridge, Natural Sciences Tripos, Part III Particles (2009) (URL: http://www.hep.phy.cam.ac.uk/~thomson/lectures/partIIIparticles/Handout12_2009.pdf)

[7]Carl D. Anderson. *The Positive Electron.* Phys. Rev., **43** 491 (1933)