Measuring The Effects Of Muons Produced By Cosmic Rays On Superconductors

2024 Beamline for Schools (BL4S) Proposal

Team Supermuons

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1 Introduction

The Earth is constantly bombarded by high-energy particles from cosmic rays. The majority of particles that hit the surface are muons, traveling with an average energy of 4 GeV [1] and a flux of $60 - 70\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$ (roughly $10,000\ \mathrm{min}^{-1}\mathrm{m}^{-2}$)[2].

Muons are known to limit the stability of qubits in quantum computing [3], yet little other research has been done on their impact on superconductors, which show promise in playing critical roles in many technologies including power lines, medical devices, generators, and quantum chips [4].

2 Why we want to go

As a group of six students from the United States, we often felt, like many of our peers, that the physics we learned in the classroom seemed detached from the "real world." But that didn't stop us.

Our research led us to BL4S, as we determined that no other initiative provides high school students with the opportunity to work with the resources and flexibility offered by the T9 beamline at CERN and DESY II beamline at DESY.

We hope our story and experiment will not only contribute to the field but also ignite a passion in our community, demonstrating that anyone — even high school students — can come together to make a meaningful difference in physics.

3 Experiment proposal

3.1 Aim of the experiment

In our experiment, we aim to discern the effects of high-energy muons on YBCO bulk superconductors, a material with potential applications in high-temperature superconductivity.

3.2 Setup

The CERN T9 beamline can accelerate muons [5]. Figure 1 depicts our experimental setup.

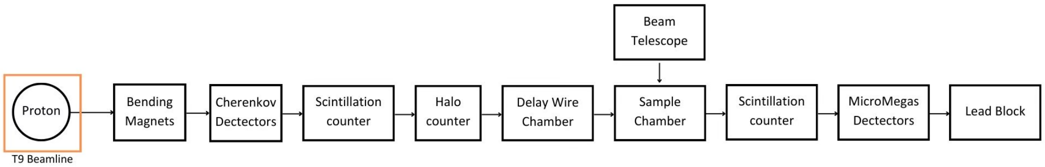

Figure 1: Proton beam is generated with proton synchrotron. Through bending magnets and Cherenkov detectors, muons are separated and filtered, attaining our desired muon beam. A scintillation counter attached to photomultiplier tubes is used to profile the beam, ensuring proper energy. A halo counter is employed to filter out deviating particles, ensuring a pure beam. A DWC measures the locations of interaction between the particles and the sample. The target itself is a chamber built to house a sample of YBCO bulk in a controlled experiment, mimicking conditions encountered during cosmic ray exposure. Beam telescope detectors are used to track the changes in the trajectory of the particles after contact with the YBCO. A second scintillation counter is used to measure the velocity of the particles after passing through the sample. Lastly, a MicroMegas detector is used to provide a higher resolution to measure the scattering angle and behavior modification of the particles after hitting the YBCO.

3.3 Methodology

3.3.1 Sample Synthesis

To produce a consistent combination of materials, Yttrium (II) Oxide (Y_2O_3), Barium Carbonate ($BaCO_3$) and Copper Oxide (CuO) are utilized over stoichiometric ratios. This blend is then thoroughly homogenized after being precisely weighed. Following the homogenization, the blend is then placed in a furnace at temperatures as high as 900°–950°C where it interacts with an environment of pure oxygen. Barium carbonate decomposes into Barium Oxide, and this is where the formation of YBCO starts, aided by Copper Oxide.

After calcination, the resulting YBCO powder is ground. The grinding is necessary because a uniform particle size distribution is crucial in the process of making sintered pellets. Therefore, the standing order is mixed, ground, mixed again if necessary because of gradations, pressed, and then sintered. The last step is annealing. The term sintering itself does not refer only to a process done under high temperatures, but also high pressures. The numbers are not very high, but the essence of the process is pressure to form YBCO pellets [6].

For time concerns, we might order pre-made YBCO bulk superconductors from laboratories.

3.3.2 Experimental setup

In order to accurately recreate the intensity of galactic cosmic radiation (GCR) due to muons (assuming a vertical incident angle), we use the energy levels of muons at sea level outlined in Table 1. We will use the parameters in specified in Table 1 (calculated using [7], [8], and Eq. 1) for the beamline.

$$D = \Phi \cdot (\frac{\mu}{\rho}) \cdot \overline{E}_{ab} \tag{1}$$

Where D is the dose rate, Φ is fluence, $\frac{\mu}{\rho}$ is the mass attenuation coefficient, and $\overline{E}_{ab}$ is the energy absorbed by the sample from the beamline.

We opted for a dose absorption rate that is similar to the yearly effective dose rate of muon radiation at sea level (as opposed to higher intensities) for a short period of time (1 hour), since we want to limit temperature fluctuation in the sample. Furthermore, we will attach the specimen to a copper water block to reduce temperature fluctuation in the sample. The sample chamber will be kept at 298 K.

The following table lists the attenuation values gathered from XCOM simulation software. Fluence values are obtained from [8].

Energy (GeV)	Fluence ($\text{cm}^{-2}\text{s}^{-1}$)	Attenuation (cm^2g^{-1})	Dose Rate ($\text{mSv}\cdot\text{s}^{-1}$)	Effective Dose (mSv)
0	—	—	—	—
1	$(1.69 \pm 0.05) \times 10^{-3}$	6.59×10^{-2}	3.17×10^{-11}	1.14×10^{-7}
2	$(7.92 \pm 1.31) \times 10^{-4}$	6.72×10^{-2}	1.70×10^{-11}	6.12×10^{-8}
4	$(5.06 \pm 0.12) \times 10^{-4}$	6.81×10^{-2}	2.21×10^{-11}	7.96×10^{-8}
6	$(1.80 \pm 0.06) \times 10^{-4}$	6.84×10^{-2}	1.18×10^{-11}	4.24×10^{-8}
8	$(9.59 \pm 0.36) \times 10^{-5}$	6.85×10^{-2}	8.41×10^{-12}	3.03×10^{-8}

Table 1: Values for fluence, mass attenuation coefficient of sample, dose rate, and effective dose at different beam energy levels. Values from [7], [8], [9].

3.3.3 Characterization

Analysis of Surface Morphology by Scanning Electron Microscopy (SEM): To observe and document the surface morphology of YBCO bulk to detect any physical alterations or defects induced by irradiation.

Analysis of Crystalline Quality by X-ray diffraction (XRD): To evaluate the crystalline structure and phase orientation of YBCO bulks and to detect any radiation-induced changes in crystallinity.

Physical Property Measurement System (PPMS): To measure the superconducting transition temperature (Tc) and the critical current density (Jc) of YBCO samples.

Superconducting Quantum Interference Device (SQUID) Magnetometry: To measure the critical magnetic field (Hc) of the YBCO samples.

4 What We Hope to Take Away

In this experiment, our primary goal is to uncover the intricate effects of cosmic ray components, specifically muons, on the fundamental and technological aspects of YBCO bulk superconductors. Through an experimental setup involving irradiation and characterizations, we aim to elucidate changes in the superconducting properties, surface morphology, and crystalline structure of YBCO.

The insights garnered will not only contribute to a deeper understanding of superconductors under cosmic radiation but also pave the way for the development of more resilient superconducting materials for advanced space technologies.

4.1 Proposal of Joint Outreach Program

Our team is excited to organize "Superconductors in Space: Navigating the Cosmos," an outreach activity designed to engage high school students in our community with the fascinating world of superconductors and their pivotal role in space exploration. Through interactive presentations, hands-on demonstrations such as levitating magnets to showcase the Meissner effect, and enriching Q&A sessions with experts in the field, we aim to simplify complex scientific concepts and spark interest in material science and physics. By providing a glimpse into how our research on the effects of cosmic ray components on YBCO bulk superconductors could revolutionize space technologies, we hope to inspire the next generation of scientists to explore the vast possibilities within these disciplines, fostering curiosity and encouraging them to consider careers in these cutting-edge areas of science. This educational event will serve as a platform for students to connect classroom physics to real-world applications, demonstrating the impact of scientific inquiry and innovation on future technological advancements.

5 Acknowledgements

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6 Appendix

6.1 Preliminary Proposed Schedule

Days 1-4: Set up experiment
Day 5: Control run and calibration test with protons or electrons
Day 6-7: Muon run at 5 energies
Day 8-11: Contingency/data analysis